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CONTENTS

THE DEVELOPMENT OF EGG-FRAGMENTS. Professor T. H. Morgan. .. 561

THE RÔLE OF THE INTERNIST IN ENDOCRINOLOGY. Dr. Thomas Sprunt 580

BAIRD THE NATURALIST. Dr. C. Hart Merriam 588

BUSINESS STRATEGY IN NATIONAL AND INTERNATIONAL POLICY. Dr. John F. Crowell 596

PAINTING THE TOWN RED. Professor T. F. Crane 605

THE ORIGIN, NATURE AND INFLUENCE OF RELATIVITY. Professor George D. Birkhoff 616

THE EARLY HISTORY OF TERRESTRIAL MAGNETISM IN THE UNITED STATES. Dr. Louis A. Bauer 625

SCIENCE TEACHING IN SOME EUROPEAN SCHOOLS. Dr. Elliot R. Downing 628

THE VACUUM—THERE'S SOMETHING IN IT. Dr. W. R. Whitney 639

THE PROGRESS OF SCIENCE: Ernest Fox Nichols; A Lactic Acid Theory of the Universe; Predicting the Movements of Electrons; The Astronomy of the Atom. Dr. Robert A. Millikan 659

INDEX TO VOLUME XVIII 671

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THE SCIENTIFIC MONTHLY

JUNE, 1924

THE DEVELOPMENT OF EGG-FRAGMENTS[1]

By Professor T. H. MORGAN

COLUMBIA UNIVERSITY

THE study of isolated blastomeres has shown that they continue to divide as though still in contact with their fellows, and that whole embryos of half size develop in some cases but incomplete embryos in others. These results demonstrate that the conditions determining the form of the later cleavage are already present after the completion of the first division of the egg. How much before this time the future course of events has been determined, so far at least as the cleavage is concerned, has been studied by cutting the egg into fragments, both before and after the entrance of the spermatozoon.

In those eggs in which the large egg-nucleus is present when the egg is removed from the female and in which the extrusion of the polar bodies takes place after its removal, there is given an opportunity of finding out whether, during this period, alterations are taking place that condition the cleavage pattern. In these same eggs, as well as in those in which the polar bodies have been already extruded when they are obtained, there is an opportunity of finding out how far the cleavage pattern is determined after the entrance of the spermatozoon into the egg. The study of fragments has also shown to what extent the cleavage pattern is foreshadowed as the time approaches when the first division is about to take place.

The earliest observations on egg fragments were made on pieces of the sea urchin's eggs (Hertwig ('87) Driesch, ('96) Morgan ('94) Delage ('99) Boveri ('89, '95, '14, '18)). The pieces were obtained in most cases by violently shaking the eggs until they were fragmented. This method is not well suited to bring out the essential relations involved, both because the situation of the frag-

[1] Chapters from Experimental Embryology. VI.

ment in the egg from which it came is not known, and because in the sea urchin the observations are limited to the period after the polar bodies have been formed. More significant results have come from the study of egg-fragments of Cerebratulus (Wilson ('03), Zeleny ('04), Yatsu ('04)); of Dentalium (Delage ('99) and Wilson ('04)); and of Beroë (Driesch and Morgan ('95), Yatsu ('10, '12), Fischel ('98, '03)).

The Development of Fragments of the Egg of the Nemertean Cerebratulus

The egg of Cerebratulus when taken from the worm at the height of the breeding season contains a large egg nucleus (Fig.

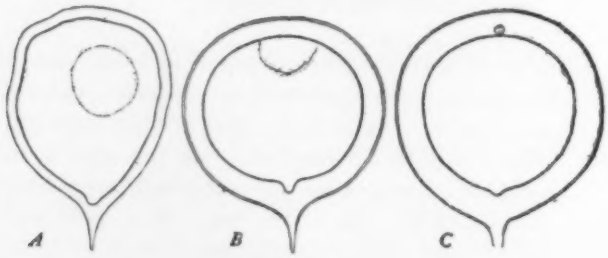

Fig. 1

1 A). The egg is slightly oval in shape and there is an extension of its protoplasm at the antipole that is the remnant of the stalk that attached the egg to the wall of the ovary. With a fine, sharp

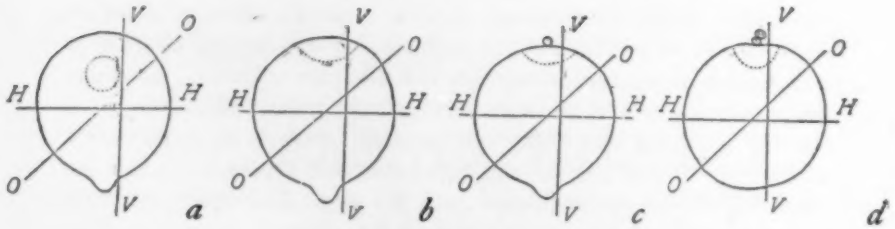

Fig. 2

scalpel the egg may be cut in two in any desired plane (Fig. 2, a–d). Owing to its viscosity both fragments remain intact, and soon round up into a spherical or nearly spherical shape. One fragment contains the egg-nucleus, the other is without a nucleus. The nucleus of the former proceeds to resolve itself into the first polar spindle. When the metaphase stage is reached further progress stops until a spermatozoon enters the fragment. In this respect the nucleated fragment behaves in the same way as an intact egg. The subsequent history of the fragment may be briefly told. It segments

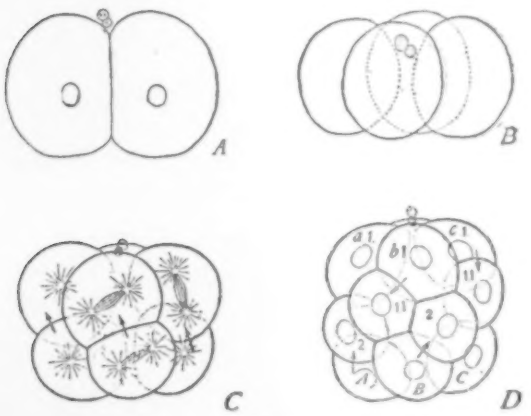

FIG. 3

(Fig. 4) in the same cleavage pattern as does the whole egg (Fig. 3). The blastomeres have the same relative size relations as have those of the normal egg or in other words the cleavage is proportional. At the third division of the normal egg (Fig. 3, C) the spiral type of cleavage appears, and the fragments also divide at this time in a right-handed spiral (Fig. 4, C, D). This result is the same regardless of the region of the egg from which the fragment came. In some cases, as shown in Fig. 4, C, the cut was "horizontal" and in other cases "vertical" (Fig. 4, A) and in others "oblique"; nevertheless, the cleavage pattern was the same in all cases. This result shows that prior to the breaking down of the egg-nucleus there were no regional differences present in the egg that determine the form of its cleavage. From these fragments, if not very small, normal embryos develop that are miniature copies of the whole embryo (Fig. 5, B and D).

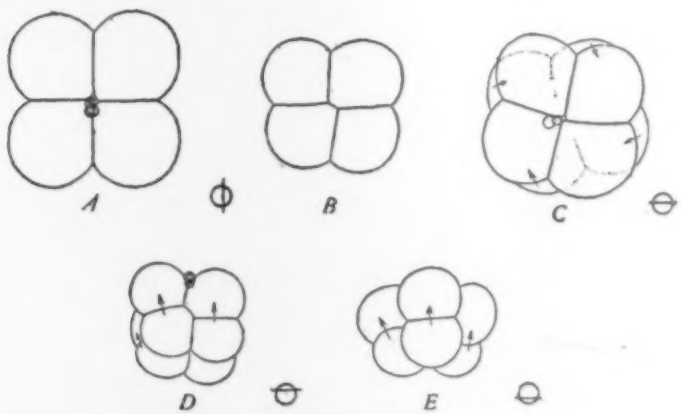

FIG. 4

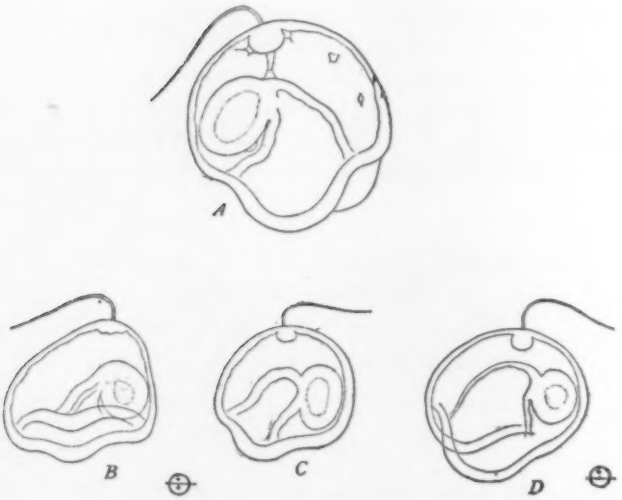

FIG. 5

The other piece of the egg—the one without a nucleus—can also be fertilized by a spermatozoon. It, too, shows in the normal cleavage pattern (Fig. 4, B, E). Since its nucleus is derived solely from the head of the spermatozoon the fragment contains only half the full number of chromosomes (haploid). This condition, however, does not affect its mode of cleavage. It is true that the haploid nature of the fragment has not been proven in this case, but since its cleavage is said to be synchronous with that of the other piece, there can be little doubt of the interpretation. This haploid fragment also forms a normal embryo—if not too small—irrespective of the way in which the fragment was removed (Fig. 5, C).

If, instead of fertilizing the fragments as soon as obtained, the operation is delayed until the first polar spindle in the nucleated fragment has developed, the results are the same as before, from which it follows that during this interval no changes have taken place that affect the cleavage pattern.

In order to study the later phases it is necessary to first fertilize the egg and wait until the first polar body has been given off and then cut the egg. The results from the nucleated piece, if it also contains the sperm head, are the same as before, and this is also true if the cut is not made until the second polar body has been extruded.

THE DEVELOPMENT OF FRAGMENTS OF THE EGG OF THE MOLLUSC DENTALIUM

Delage ('99) cut 18 unfertilized eggs of Dentalium into two pieces, and in six cases both fragments segmented. The first

cleavage was only "rarely" into two equal parts; more usually the fragment divided at once into four parts. It is probable that these fragments are polyspermic or that Delage mistook the yolk lobe for a blastomere.

Unfortunately, no information is given as to the details of the cleavage or as to the type of cleavage of the nucleated and non-nucleated fragments. Normal as well as abnormal embryos were obtained from both kinds of fragments. Information that is lacking in Delage's account is supplied by the later work of Wilson ('04) and the following statements and illustrations are taken from his paper. The eggs were cut in two with a scalpel, and the fragments were then fertilized. Both pieces often segmented. In the figures (7–9) the position of the cut is indicated by the smaller circle near each picture of the cleavage, and the piece that divided is indicated by a black dot. The upper part of each of these small circles indicates the pole. The egg nucleus after the extension of the polar bodies lies in this region. The polar bodies are given off from the polar fragment after the operation. Their presence makes it possible to determine which of the two fragments contains the egg nucleus as well as its regional relations. The normal cleavage of Dentalium is shown in Fig. 6. The presence of the yolk lobe that first appears at the time of the first cleavage and which remains attached to one of the blastomeres (D) makes it possible to follow in detail several interesting features in the cleavage of the fragments and to compare them with the cleavage of the whole egg.

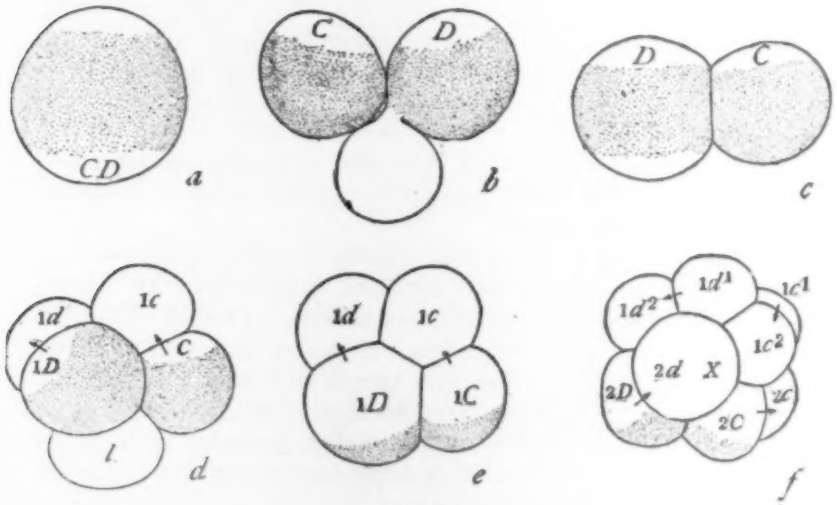

FIG. 6

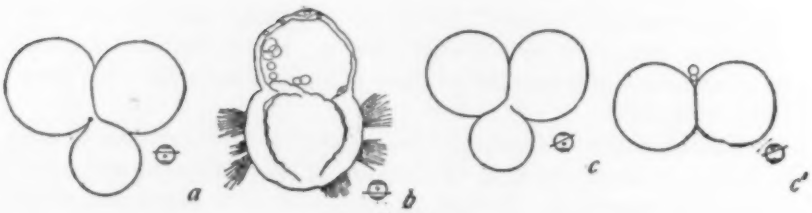

FIG. 7

When the unfertilized egg is cut in two nearly equal parts in a horizontal plane (Fig. 7, c′), and then fertilized, the polar nucleated fragment divides into equal parts as does the normal egg, except that no basal lobe appears. The second cleavage is again equal. The succeeding cleavages are spiral, quartets of micromeres being formed by alternating dexiotropic and leiotropic divisions. Many of the embryos fail to develop, but others develop into actively swimming trochophores (Fig. 7, b) that are never quite normal. These larvae sometimes agree precisely with those derived from whole eggs from which the basal lobe has been removed. These will be described later. In a few cases an apical organ is present. When the upper fragment is larger than the lower one, it may form a small basal lobe.

The lower (basal or antipolar) fragment (Fig. 7, a) may segment "in every detail like an entire egg of diminished size, forming the polar lobe in normal fashion, and may give rise to a dwarf larva nearly or quite normal in form and possessing an apical organ" (Wilson). Moreover, while there is much variability in the size of the polar lobe, it is often of exactly proportionate size, even when the section has passed above the limits of the white antipolar field. The form of the cleavage is, within limits, independent of the size of the piece, that is, both large and small fragments (¼ full size) may segment as wholes (Fig. 7, a–c). Many of the embryos perish, and of those that live many are abnormal, but occasionally a dwarf embryo is produced that is a normal trochophore except in size.

When the egg is cut in two, parallel to the primary axis, *i.e.*, vertically, and the fragments fertilized, both halves may develop (one diploid, the other haploid), both produce a lobe, since the antipolar white field was cut in two. A case of this kind is shown in Fig. 8, a, a′, b, b′. The yolk lobe is sometimes relatively too small, but in other cases it may be of proportionate size. Some of the larvae from such a vertical section approach in form the normal trochophore and without doubt normal embryos can be obtained from such fragments.

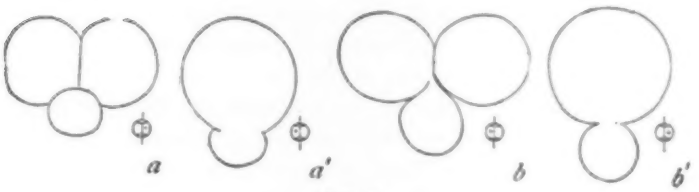

FIG. 8

The preceding statements apply to eggs cut before fertilization and subsequently fertilized. Eggs were also operated on after the first or second polar bodies had been given off, therefore after fertilization. Only the fragment with the egg nucleus segments. If cut horizontally, the polar nucleated piece segments as a whole egg, but without the basal lobe. The larva is normal. The behavior of the basal non-nucleated piece is most remarkable. "It forms three times in succession a polar lobe from the white area at the same time that the nucleated half is dividing." This change is comparable to that shown by the lobe itself when cut off from a whole egg. It shows periods of activity that are synchronous with the cleavage of the egg from which it was removed. The lobe may even form a smaller lobe that simulates the lobe of the normal egg.

Normal entire eggs from which the lobe is cut off continue to segment in the normal fashion except that no lobe reappears, and the D quadrant is no larger than the others. Such embryos gastrulate and give rise to swimming larvae, but the post-trochal region is absent and they show no trace of an apical organ. The absence of the apical organ and of other organs normally present in this region is not due to the decreased size, since still smaller embryos from basal fragments produce these parts. Wilson concludes that the results are due to some materials present in the lobe itself that are essential for the development of even the apical organ.

THE DEVELOPMENT OF FRAGMENTS OF THE EGG OF THE CTENOPHOR, BEROË

It was shown by Driesch and Morgan ('95) that fragments of the unsegmented eggs of Beroë segment sometimes as wholes and sometimes as parts of wholes. They surmised that this difference

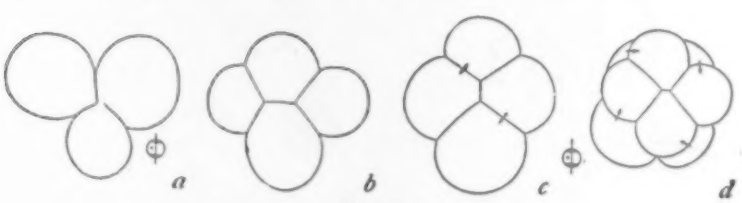

FIG. 9

might depend on whether the cut was symmetrical with respect to the pole or on one side; and the later experiments of Yatsu have shown that this is true, if the cut is made when the first cleavage is about to take place, but for oblique cuts the differences in the type of cleavage depend on the time at which the operation is performed. The cleavage of fragments of the egg of Beroë was later studied more in detail by Yatsu ('11, '12), and to a limited extent by Fischel ('98, '03) and Ziegler ('98).

Yatsu cut unfertilized eggs soon after being laid (the plane of the section was not determined) and, in the two cases examined, the cleavage was normal. After the two polar bodies had been extruded other eggs were cut in various planes. Three eggs were cut vertically, *i.e.*, parallel to the egg axes. Normal cleavage followed, although the middle and end cells on the cut side were somewhat smaller than their vis-a-vis, but the micromeres were the same in all (Fig. 10, a). Six eggs were cut obliquely (Fig. 10, b) with results

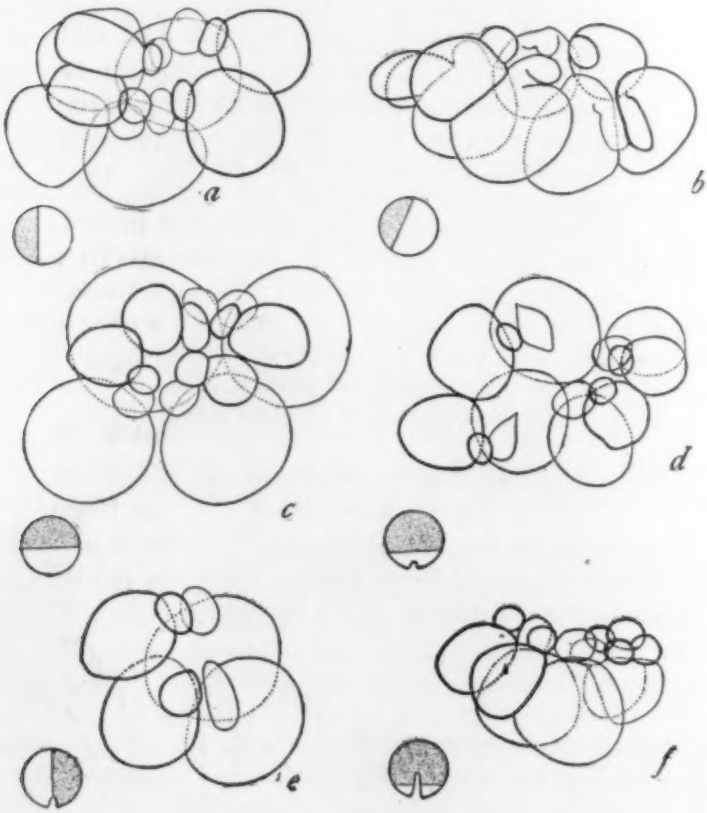

FIG 10

as before. One egg was cut horizontally (Fig. 10, c). The end cells were small, but the micromeres were almost as large as in the normal egg.

At the beginning of the first cleavage three eggs about to divide were cut horizontally (Fig. 10, d). The small polar fragment divided normally. Seven eggs were split in two in the plane of cleavage (Fig. 10, e). The fragment cleaved as a half. Further experiments of the same sort—more especially after the first cleavage had progressed some distance—were undertaken by Yatsu to see how far the subsequent divisions give "proportionate" cleavage patterns. Most of the sections were horizontal, and only the nucleated fragment segmented (Fig. 10, f). Even when the polar end was cut off after the cleavage head had passed beyond the plane of section (Fig. 11, b, e, d), the fragment gave a proportionate, whole cleavage. This is all the more surprising when it is recalled that if the dividing egg is cut in two in the plane of division each half cleaves as a half. It is evident, however, that in the latter case each half is more like the normal half blastomere and the mitotic figure is the same and the material is the same as that of the half blastomere; while in the former case the small polar fragment contains the two nuclei with their surrounding materials (although much reduced in volume) and these are symmetrically placed around the pole. If the size of the mitotic spindle is dependent on the cell content, and if the cleavage is determined by the spindle rather than by the material of the cytoplasm, one can under-

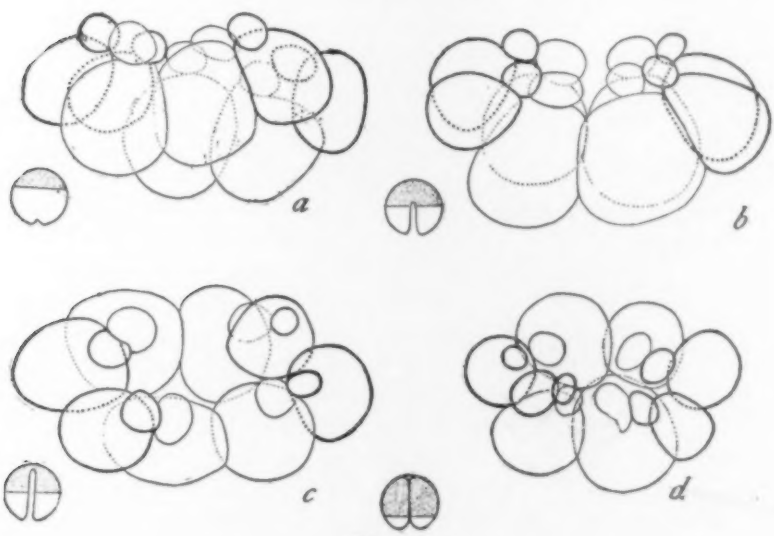

FIG. 11

stand to some extent, at least, why the cleavage of these polar fragments is proportional.

There is another important fact shown by these experiments of Yatsu. If the section is made when the first cleavage is just beginning, the nucleated (polar) end contains a great part of the ectoplasm that at this time has moved into the polar region, yet the micromeres are no larger than in the case when the section is made towards the end of the first cleavage at which time much of the ectoplasm has left the polar region and moved into the antipolar field. Evidently, the amount of ectoplasm is not in itself the factor that determines the size of the micromeres, although in the normal egg they appear to be largely composed of this material.

The Development of Fragments of the Eggs of Sea Urchins

The experiments with fragments of the sea urchin's eggs were the first of the kind to draw general attention to the importance of this method of studying the changes in the egg prior to its cleavage. The work of Boveri ('89, '95, '14, '18), Morgan ('94, '95), Driesch ('96), Delage ('99) on the sea urchin's egg showed that the nucleated fragments of this egg may develop into whole embryos of small size. It was also found that even the non-nucleated fragments might also divide if entered by a spermatozoon, and it was supposed that they also might produce small embryos.

If the eggs of the sea urchin are shaken violently in a small tube before fertilization they may be broken up into fragments of various sizes; some of the fragments contain the egg-nucleus, others are without a nucleus. The fragmentation is more easily brought about immediately after fertilization. We do not know explicitly how each of the two kinds of fragments behaves, but it is known that the fragments that contain both the egg-nucleus and the sperm develop, while those that contain only the sperm may segment and the larger ones at least are supposed to gastrulate and even produce plutei.

The cleavage of egg-fragments of sea urchin's eggs, obtained before fertilization, has been studied by Morgan ('93), Driesch ('96) and Delage ('99). Morgan described the cleavage as very irregular. The pattern was not like that of the whole egg. Driesch examined eggs of two sorts. One lot of eggs was shaken an hour after fertilization, hence just before its first cleavage is expected. Seven types of cleavage patterns were found; all "partial" or irregular. Some of the larger pieces especially showed at times a close approach to half cleavage. Driesch ascribes the different types observed to the fragments coming from different regions of the egg, and since the eggs were fragmented just before the first

cleavage is due this seems a probable explanation in the light of evidence from other sources. Driesch also studied the cleavage of eggs that were broken into fragments before fertilization. He found that these fragments also showed great variability in their cleavage pattern. The same types that he had obtained from fragmentation of later stages (described above) reappeared here also. In a few cases, especially in the larger fragments, normal cleavage was observed. He concluded, nevertheless, that partial and not whole cleavage is the rule and inferred that the cleavage pattern is predetermined in the egg.

Delage cut each egg into two parts—a method that is better suited to give an answer to the question involved. The fragments were then fertilized. In six cases both fragments divided. Delage states that "the cleavage takes place as in the normal egg," but no details are given and, judging from the result he records for fragments of other kind of eggs, it seems probable that Delage did not follow the cleavage in sufficient detail to answer the question as to whether the characteristic features of the cleavage were those of the whole egg.

From the foregoing evidence it is uncertain whether fragments of the sea urchin's egg obtained after the polar bodies have been extruded, but before fertilization, segment as parts or as wholes. It is quite possible that the rough treatment employed when the eggs are broken by shaking injures them or disturbs their structure to such an extent that the irregularities observed in the cleavage are due to disturbance of the structure rather than that they represent partial cleavage. The method of cutting the egg is undoubtedly better and might be expected to give the information called for, but Delage's statement is too vague to be satisfactory.

That the cleavage of fragments obtained just before cleavage should be partial is, as I have said, very probable and is due to changes that have begun in anticipation of the normal cleavage. On the other hand, if the fragments from earlier stages had segmented as wholes we should expect this to have been seen at once by the several observers on the cleavage of such fragments. In the absence of such observations, I am inclined to believe, with the reservations spoken of above, that the cleavage pattern of these fragments is partial and that it is due to changes that have taken place after the polar bodies were extruded.

Fertilization of Non-nucleated Fragments of the Egg of One Species of Sea Urchins by Sperm of Another Species

Boveri ('89, '95, '14, '18) carried out the ingenious experiment of fertilizing the non-nucleated fragments of an egg of one species of sea urchin by sperm of another species in order to discover

whether the characters of the larva are determined by the protoplasm or by the nucleus or by both.

It is true that this question is to-day definitely settled by Mendelian crosses where single differences are involved, and unless there is something unknown and peculiar where species are concerned there is every expectation that, given sufficient time, the nucleus will determine the character of the structures produced by the cytoplasm, but when, in 1889, Boveri first made his experiment all this was not known or at least not appreciated. Boveri himself held later ('06) that "fundamental characteristics" of the organism are determined by the cytoplasm, while the smaller details in which species differ from each other are regulated by chromosomal activities. But this point is scarcely involved in the experiment in question, since the "fundamental" structures are the same in both species of sea urchin used for the experiments. The real question to-day is only whether the influences under which the cytoplasm of the egg has been produced will affect the character of a pluteus that contains a nucleus of another species. Boveri's experiments were made with the eggs of Sphaerechinus fertilized by the sperm of Echinus. The normal pluteus of Echinus is shown in figure 12, a and d in side and in front view; that of Sphaerechinus in figure 12 c and f; and that of the hybrid in figure 12 b and e. A hybrid pluteus of "pure" Echinus type from an egg fragment of Sphaerechinus fertilized by a spermatozoon of Echinus is shown in figure 12 c, and two views of another similar hybrid are shown in figure 13 a and b. Most of the small plutei that developed from cross-fertilized fragments were intermediate in form and in the structure of their skeleton, but a few were found that were like those in figure 13, that were purely paternal, and these Boveri concluded were derived from the non-nucleated egg fragments of Sphaerechinus that had been fertilized by the sperm of Echinus. He concluded from this evidence that the nucleus determines the character of the pluteus, even when the cytoplasm belongs to another species, in so far as the two species in question differ from each other.

The validity of Boveri's evidence was questioned by Seeliger ('95, '96) and by Morgan ('95) on the grounds that the full-sized hybrid plutei derived from this cross sometimes produced larvae whose skeletons are purely paternal. Boveri's general conclusion was not challenged, but the evidence for it was questioned. In fact, while it seems highly probable that paternal larvae might sometimes be produced in this way depending in the main on how far the earlier influence on the cytoplasm carried over to the pluteus stage, yet the evidence to prove this was inadequate under the

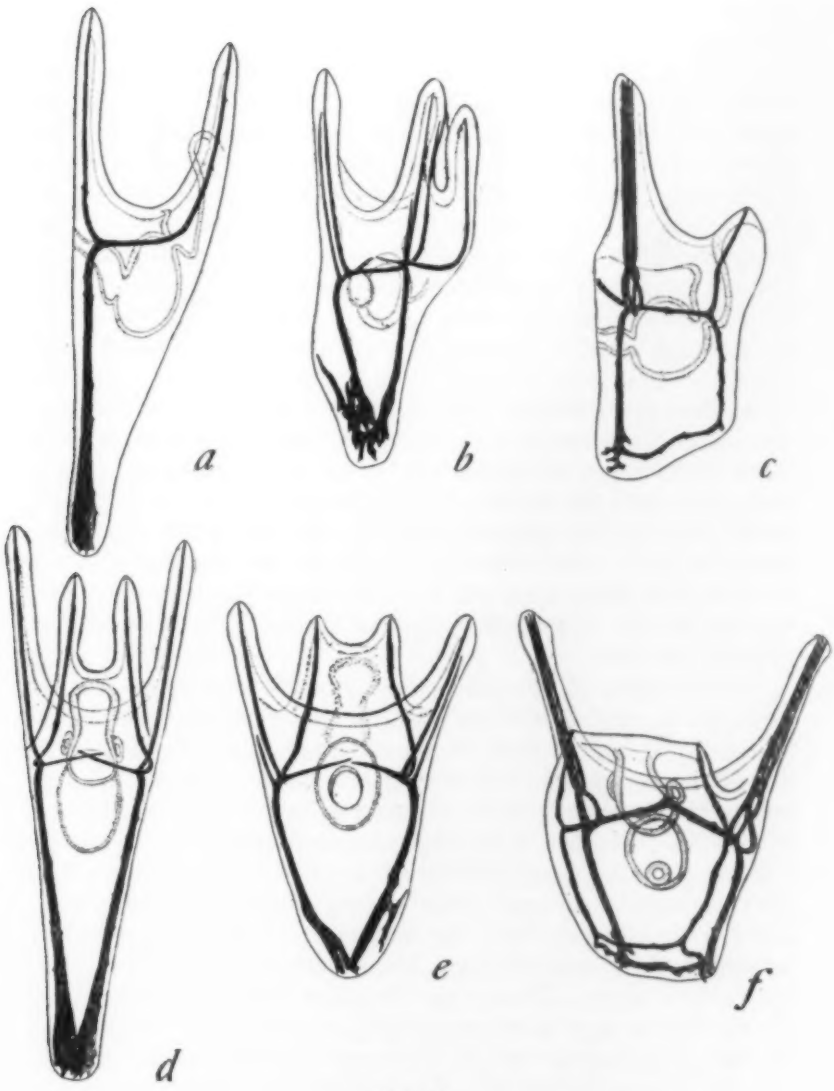

FIG. 12

conditions of the experiment. Boveri was loth, at first, to recognize the value of the evidence advanced by Seeliger and Morgan, but in his last paper is more inclined to give credence to it. In fact, he later concluded that the hybrid plutei with paternal skeleton had indeed come from nucleated fragments.

Boveri continued for several years to search for convincing evidence to settle this question. He tried out especially the method

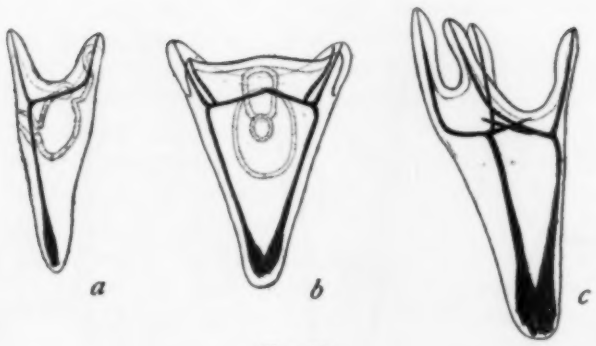

FIG. 13

of isolating fragments of eggs in which no nucleus could be seen. This work is extremely laborious and disheartening, since even when embryos are obtained few of them reach the pluteus stage. It was not until the winter of 1911–12 and again in 1914 that he finally obtained the evidence he sought. The new results were published in 1918 a year after his death. He had found that none of the hybrid larvae from non-nucleated fragments develop beyond the late blastula or early gastrula stage; hence do not furnish the evidence required.

In the course of this work Boveri went so thoroughly into all sides of the question involved that his procedure will stand as a model of the highest type of embryological inquiry. It showed throughout a freedom from bias, a critical thoroughness of procedure and a resourcefulness of methods that call for the highest admiration. The clue to the final solution Boveri found in a more detailed study of the fragments of the Sphaerechinus eggs that were apparently without nuclei. Most of these fragments produced sickly blastulae that went no further, or at most formed the beginning of the gastrula stage, but in addition there were a few well-formed plutei. These were not all of paternal form, but on the contrary most of them were clearly intermediate in their skeletal form as in the case when an entire egg of Sphaerechinus is fertilized by a sperm of Echinus. These plutei were killed and stained, and it was found that their nuclei were as large as those of a hybrid from an entire egg. In other words, they were diploid. It seemed probable, therefore, that the supposedly non-nucleated pieces had really contained the normal number of chromosomes. Delage, in fact, had noted earlier that an apparently non-nucleated fragment might contain the constituents of the nucleus, if the nuclear wall had broken down as a result of the shaking. Boveri also found later that when the eggs of Echinocardium are shaken the nucleus disappears from view in many eggs, but when killed and

stained a deep mass of chromosomes could be detected, as Morgan had earlier shown for starfish eggs. This mass resolves itself into its constituent chromosomes when the egg is fertilized, and combining with the sperm nucleus forms a normal segmentation nucleus. Baltzer ('10) had in the meanwhile repeated the experiments of isolating supposedly non-nucleated fragments, crossing them with sperm of another species, and had found that all but two died as blastulae. The two that became plutei when stained were found to contain full-sized (diploid) nuclei, and must, therefore, have contained originally chromosomes derived from the egg.

Boveri ('18) repeated his isolation experiments once more. Two hundred egg fragments apparently without nuclei were isolated. From them eleven well-developed plutei were obtained. Eight of them had large nuclei, and the fragments from which they came must have had invisible maternal chromosomes when isolated. Of the three remaining plutei two had both larger and smaller nuclei. They were, therefore, of doubtful origin and may have come from partially fertilized egg-fragments, or from eggs whose nuclei had been in the form of isolated vesicles as rarely occurs. The third pluteus having small nuclei showed probable indications of hybrid origin in its skeleton and is, therefore, also of doubtful value as evidence.

Finally, Boveri returned once more to mass cultures of egg-fragments. Eggs of Sphaerechinus were broken up and fertilized in some cases with Echinus sperm, in other cases with Strongylocentrotus sperm. At intervals large numbers of fragments were preserved. Judged by the standard of nuclear size, he found that both the fertilized non-nucleated and nucleated fragments develop at first at the same rate. But when the blastula stage is finished the small nucleated fragments cease to develop, while the others go ahead to form plutei. The oldest of the small-nucleated embryos stopped developing during the gastrula stage—only two showed traces of the triradiate spicules. This evidence, added to the rest, shows that the non-nucleated fragments, fertilized by the sperm of the other species, are unable to reach the pluteus stage. It seems probable that the foreign nucleus alone is unable to impress its characteristics on the cytoplasm that has developed under the influence of its own nucleus. But why it fails to do so is not at all evident in the light of the characters of the hybrid pluteus from whole eggs that are intermediate. Here the paternal chromosomes even in the presence of the maternal chromosomes are able to affect the character of the hybrid pluteus.

One further source of evidence must be added before attempting to interpret these results. Non-nucleated fragments of Sphaere-

chinus fertilized by their own sperm are able to produce plutei that have, of course, the characteristics of the species. Furthermore, Boveri found ('12) that the non-nucleated fragments of Sphaerechinus eggs fertilized by the sperm of a closely similar species, Strongylocentrotus, also produced plutei. The plutei of these two species are so similar that it is not possible to determine whether the hybrid monospermic (small-nucleated) plutei are more paternal than the hybrid pluteus. Nevertheless, the result shows that the nucleus of one species and the cytoplasm of another species may combine to form a pluteus. Why, then, does not the more extreme combination develop as far? We can only conjecture that it is because of some secondary failure of this combination to reach this stage. It does not seem to be due to any very "fundamental" conflict between the nucleus and the cytoplasm.

In the light of his own results Boveri considers adversely the evidence that Godlewski has furnished relating to the fertilization of supposedly non-nucleated fragments of the eggs of the sea urchin, Echinus, by the sperm of the crinoid, Antedon. Godlewski ('06) found that, while most such fragments died after fertilization in early stages, four reached the gastrula stage, and that these were of purely maternal type. This means that the foreign sperm had

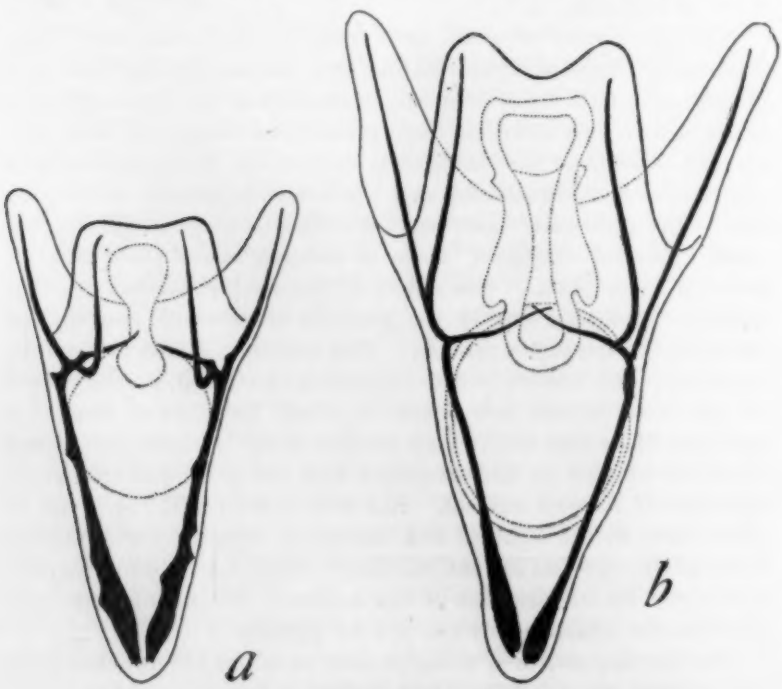

FIG. 14

failed to impress on the protoplasm the particular gastrulation type of its species. The gastrula stages are so different in the sea urchin and crinoid that it ought to be evident whether the gastrula followed one or the other method of development.

Since Godlewski made no measurements of the nuclear size, Boveri believes that there can be no doubt but that these supposedly haploid gastrulae came from fragments whose chromosomes were present even though invisible in the living fragment. The probability of the correctness of Boveri's diagnosis is very great in the light of the other evidence furnished by Godlewski and by Baltzer, namely, that the hybrids from whole eggs (Fig. 14, b) are also strictly maternal.

The Development of a Part of the Egg of the Salamander, Triton

Spemann ('19) obtained an embryo that developed from a part of a triton's egg that contained one sperm. His method was as follows: A hair was tied around the egg immediately after fertilization and tightened until the egg was constricted into two parts of unequal size. More than one sperm enters the egg of triton as a rule. The point of penetration is often marked by a light fleck on the surface. The location of the polar spindle of the egg is also indicated by a whitish area at the pole. In one case where one portion was smaller than the other (Fig. 15), the larger portion contained the polar bodies and presumably the egg nucleus and one or more spermatozoa. The smaller portion contained a single sperm as indicated by its point of penetration (in the left hand portion of Fig. 15). Both portions began to divide and were separated later. Each produced an embryo. A repetition of the experiment gave a few other embryos. Those from the mono-

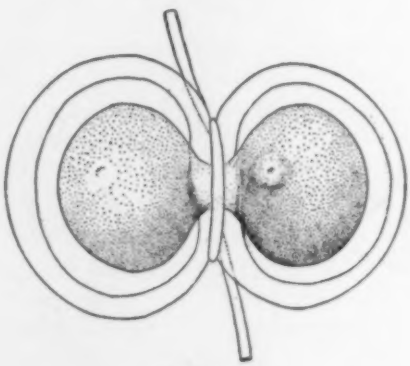

Fig. 15

spermic portion often produced embryos, but these did not live beyond the earlier stages.

Baltzer ('22) has repeated this experiment and obtained in one instance a dwarf larva that developed as far as metamorphosis when it died. It was less active than a normal larva and moved about slowly. An examination of its nuclei showed that they had only half the volume of those of a normal, or diploid triton. There is no doubt that Baltzer's larva was haploid.

In this connection the earlier results of Oscar and Gunther Hertwig ('12) must be mentioned. By treating the egg of the frog with radium they succeeded in injuring the polar spindle, so that the egg-nucleus was destroyed. When such eggs are fertilized some of them develop with haploid nuclei, but the embryos die after several days or weeks. Their cells contain nuclei that have only half the volume of those of normal embryos. Paula Hertwig ('20) has fertilized frogs' eggs that had first been denucleated by radium, with sperm of the toad. Some of these eggs developed as haploid larva, others, by delaying the first cleavage, diploid, but unfortunately neither kind went far enough to show whether they were purely paternal in their characters.

Conclusions

The study of egg-fragments has brought out certain facts of general interest to embryologists. The results have shown, for instance, that the mere entrance of the spermatozoon into the egg does not suffice to start development, for, if the egg be then cut into two pieces in such a way that the sperm-nucleus is present in one fragment and the egg-nucleus in the other, the former develops but not the latter. It follows that those theories of fertilization that have been proposed which terminate with the entrance of the sperm into the egg are entirely inadequate to explain the process of fertilization.

The study of the cleavage of fragments indicates that its pattern is not foreshadowed or predelineated in the protoplasm, but that the form of cleavage appears *pari passu* with the development of the mitotic figure in the piece. The surface conditions of the egg do not appear to condition either the type of the cleavage or the relative sizes of the cells. On the other hand the position and size of the spindles appear to determine the character of the cleavage about to take place. In fact, the proportionate type of the cleavage shown by fragments may be little more than an outward expression of the size of the spindle which in turn is an expression of the material available for its formation. If this inference is correct it calls for a further examination of the phenomenon of gelation (or

hardening) of the colloidal material of the egg that appears to be an important part of the physical expression of the mitotic phenomenon. How the alternating changes from gel to sol affect the kind of spindles that develop as cleavage follows cleavage we do not know. We must invite the assistance of the physical chemist to help us forward.

The development of embryos that contain the half number of chromosomes has been definitely established by the study of fragments that contain the sperm-nucleus, and there can be little doubt also but that a fragment containing the egg-nucleus alone, if it could be incited to divide, would also give rise to a haploid embryo. The development of whole eggs brought about by reagents that start its development prove that one set of chromosomes suffices to produce an embryo. Nevertheless, the delicacy of these haploid embryos is known both from the results of experimental embryology and from genetics. The failure of non-nucleated fragments of the egg of Sphaerechinus to develop into a pluteus, under the influence of the sperm of Echinus, does not mean that such an occurrence in general is impossible. Boveri has shown, in fact, that a haploid hybrid may be formed in another combination. The question that this experiment was intended to answer has, however, been answered by modern genetics. There is, nevertheless, another question connected with the development of haploid organisms that is most important. It appears that haploid embryos derived from whole eggs have cells relatively too large in proportion to the nuclei in them, or, in other words, that the protoplasm does not become adjusted in this respect to the chromatin. The weakness of these embryos is sometimes supposed to be the result of such a maladjustment. On the other hand, a fragment of half size with a haploid nucleus would be expected to have the proper adjustment of cytoplasm to chromatin. It has been supposed that they have, therefore, a better chance of survival. The evidence, however, is at present very incomplete, and the conclusion doubtful. A similar question arises in those instances where an egg starts its development with twice the normal number of chromosomes (tetraploid). Geneticists have brought forward several instances of this sort. There is here the reverse cytoplasmic relation. The answer to these two questions may help to solve one of the important problems of development, the quantitative relations of the cytoplasm to the nucleus.

THE RÔLE OF THE INTERNIST IN ENDOCRINOLOGY[1]

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IT is a much-appreciated privilege to participate in the proceedings of this section on the 75th anniversary of the association. What a wonderful period this has been in the history of medicine, with the development of our knowledge of bacteriology and parasitology, of infection and immunity, of aseptic surgery, of scientific chemotherapy, and with the growth of a great interest in, and a rapidly increasing knowledge of, endocrinology!

When this association was founded Pasteur had just graduated from the École normale at Paris, Lister was entering upon his student days at the University of London, Koch was a boy five years of age, Robert Graves and Basedow had published their descriptions of exophthalmic goitre, Addison was in the midst of his work on diseases of the suprarenal glands, Brown-Séquard was beginning his experimental work and Claude Bernard was giving to the scientific world his classical statement of the doctrine of internal secretions based upon his work on the glycogen of the liver. What a group of revolutionists! As Sir Michael Foster has said, Bernard's work was revolutionary in more ways than one. He demonstrated that a single organ, such as the liver, may have more than one function to perform, a view that was contrary to the dominant conception of the time, and he introduced the idea of an internal secretion, thus emphasizing the importance of the changes that the blood undergoes as it sweeps through the several tissues, changes that are so important for the health of the body through the coordination of its activities.

Although bacteria had been seen before and theories of living contagion had been formulated, it was the work of Pasteur and of Koch that caused bacteriology to flame out into a great light, which illumined all fields of medicine. The development of endocrinology was less spectacular as it was of less direct utility in the practice of medicine and no great general interest was shown in the subject until after the beginning of the twentieth century. The glands themselves, with the exception of the parathyroids, discovered in

[1] Read before Section N (Medical Sciences), American Association for the Advancement of Science, Cincinnati, Ohio, December 29, 1923.

1880, had been known to anatomists for centuries, and by the middle of the nineteenth century there were on record a considerable number of clinical and pathological descriptions in which were associated certain definite clinical syndromes with lesions of one or another of the ductless glands. Such were the contributions of Flajani, Parry, Graves and Basedow on exophthalmic goitre in the first half of the nineteenth century. Endemic goitre was known to the Romans, its association with idiocy was pointed out by Paracelsus in the sixteenth century and long before that time, Roger of Palermo taught the use of iodin in the form of sponges and seaweed in the treatment of goitre. There were other haphazard observations, such as the description by Felix Plater in 1614 of an autopsy on an infant, a victim of thymic death. Something was known of the influence of the testicular and ovarian secretions through the castration and spaying of animals, which had been practiced a very long time.

Such was the meager state of knowledge concerning the ductless glands in 1848. Bernard's work was just coming forth, Addison's famous monograph concerning the disease that bears his name appeared in 1855, and the next year the experimental demonstration by Brown-Séquard that the suprarenals are necessary for life. Then came in succession the experiments of Moritz Schiff on excision of the thyroid gland in dogs; the surgical excision of goitre in man, by Kocher; the description of myxoedema and its relationship to the thyroid; Schiff's further experiments with the demonstration of the value of thyroid administration in prevention of symptoms in thyroidectomized dogs; and Murray's adaptation of this knowledge in the successful treatment of myxoedema in man in 1891.

Similarly, in the history of pituitary studies it has been the rôle of the internist and the pathologist to correlate lesions with clinical manifestations (Klebs 1884, Marie 1886, Fröhlich 1901) and thus to stimulate experimental work by surgeons (Horsley, Paulesco, Cushing), by chemists and by physiologists (Oliver and Schäfer, Howell).

The gradual unfolding of the importance of the endocrine glands, in the maintenance of health, in the production of disease and in their influence upon growth and developmental processes, began to attract the attention of the whole medical profession, and in the present century the flame of interest in endocrinology has, in the opinion of many conservative physicians, burst forth into a conflagration that seems somewhat difficult to control. It is important to remember that the subject is still in the developmental stage, that in the enthusiasm of the moment there may be

a tendency for fancy to outstrip facts, that the point of view of one internist is not necessarily the same as another's, and that the viewpoint of each is apt to change in regard to certain details from year to year. Our knowledge of the physiology, of the pathology and of the biochemistry of most of the ductless glands is but fragmentary. Much remains to be done and the rôle of the internist in this domain in the course of his practice of medicine and in the clinical investigation of the many problems to be elucidated may be tentatively outlined as follows:

(*1*) *The clinical observations of endocrine syndromes.*

(a) The diagnosis and treatment of diseases associated with disturbance in the glands of internal secretion.

(b) The clinical trial of the methods used in animal experimentation and of the results of biochemical research that give promise of value in diagnosis and in therapy.

(c) The observation of endocrinopathies under unusual conditions and in unusual associations.

(*2*) *The clinical study of the constitution in which the endocrine glands must play an important part.*

ad 1—(*a*) Emphasis has already been placed upon the original clinical delineations by internists in this field, and it may be pointed out further, for example, that after the descriptions of exophthalmic goitre by Parry, Flajani, Graves and Basedow, it was Möbius who, in 1886, first attributed this condition to an excessive outpouring of the thyroidal secretion and that the rapid emaciation associated with the disease was explained by Friedrich Müller, in 1892, by his demonstration of the markedly increased metabolism. Similar helpful suggestions and valuable contributions to the knowledge of endocrinopathies are to be expected in the future from the careful observation and study of patients.

In routine office and hospital practice it has been found helpful to include as part of a general diagnostic survey a special endocrine note on those patients who, at the first examination, show features suggestive of endocrine disturbance. In making this note each of the important endocrine glands is considered in turn and under the heading of that gland the positive and the important negative data in each system of the body are recorded. Thus under the heading of the thyroid gland the possibly pertinent data are noted in (1) the endocrine system; (2) metabolism; (3) bones, muscles, joints; (4) the respiratory system; (5) the cardio-vascular system; (6) blood and hemopoietic organs; (7) the digestive apparatus; (8) the urogenital apparatus; (9) the nervous system, including the psyche, the organic neurological features, the autonomic

nervous system, the integument and its appendages. Similarly, in the consideration of the hypophysis, the gonads, the adrenals, etc., the possibly pertinent data are arranged systematically and at the conclusion of the examination an impression from the standpoint of this general survey of the endocrine glands and their functions is recorded. Finally, the integrator of the general diagnostic study attempts to place the proper valuation upon these data as well as upon those obtained by other examinations, to weld the several essential features brought out by the study into a more or less harmonious whole, and to outline the therapy best adapted to the needs of the particular case.

ad 1—(b) Although the practicing physician has frequently been the first to point out the association of symptoms with pathological lesions and has passed on to other practitioners this diagnostic ability, in the matter of treatment he is quite willing to come second to him who has "tried it on the dog." Animal experimentation in this as in all fields of medicine has been of incalculable benefit. It is the function of the physician to test thoroughly at the bedside and in the office the therapeutic value of promising methods inaugurated in the experimental laboratories. Thus Murray made the clinical adaptation of Schiff's thyroid substitution-therapy in dogs and showed that in man, also, the administration of thyroid products is capable of replacing, at least in part, the functioning of the normal gland; and thus very recently Best and his collaborators demonstrated the usefulness of insulin in lowering the blood sugar in man and its value as an adjunct in the treatment of diabetes mellitus, after Banting had determined its potency and the means of its control in animals. Would that similar illustrations might be applicable in the substitution therapy of other ductless glands! Much experimental work has been done and many clinical trials made with extracts of the hypophysis, of the suprarenals, of the gonads, and of the parathyroids, with varying results and many diverse opinions. But if this work has given only meager results in supplying substitutive therapy in states of hypofunction of the particular glands it has, nevertheless, increased our therapeutic armamentarium in furnishing several valuable pharmaceutical agents that are useful in the treatment of conditions not necessarily dependent upon hypofunction of the endocrine organ from which the remedy was obtained. As examples we may cite the gratifying results of epinephrin injections in the treatment of bronchial asthma and the equally favorable effects of pituitrin in diabetes insipidus, in dynamic ileus and in cases of sluggish uterine musculature. Banting's recent success in the production of a potent pancreatic extract after years of unsuccessful effort in

many laboratories is most encouraging for the substitutive organotherapy of the future.

In the treatment of patients showing endocrine hyperactivity the internist has learned a great deal from the surgeon, from the roentgenologist and from the radium therapeutist, all of whom have obtained satisfactory results in function-reduction, especially of the thyroid, of the ovaries and of the thymus, although they are less successful in similar attempts to influence hypophyseal hyperfunction and suprarenal hyperfunction. The physician, however, may often secure gratifying results in cases of endocrine hyperfunction, without calling upon his surgical colleagues, by the institution of carefully planned dietetic and hygienic regimens, with due attention to the many small details and with the help of judicious pharmacotherapy and psychotherapy. Much interest is being shown at present in the comparative studies that are being made in several clinics concerning the relative merits of surgical, of roentgenological and of medical methods in the treatment of exophthalmic goitre.

ad 1—(*c*) As an example of clinical acumen in the observation of endocrinopathies under unusual conditions, observations that may perhaps increase our knowledge of glandular physiology and pathology, we may cite the recent contribution of Curschmann upon what he considers the influence of the war diet on thyroid disease. He noticed that in Germany during the war the number of cases of exophthalmic goitre was small, that there were fewer severe cases and that these few recovered unusually quickly on the war ration and did not require surgical intervention. He states, on the other hand, that cases of hypothyroidism were more numerous than usual. Ten of the twelve German clinicians to whom he sent questionnaires replied that their experience was quite similar to his. He attributes the variation in the incidence of the disease to the meager war diet, about 1,500 to 1,800 calories per day, poor in protein (30 to 40 gm per day) and also poor in fat. Each person received from 100 to 200 gm of meat in a week and from 4 to 10 gm of fat daily. Eggs were scarce and there was no cream. His observations and interpretations are at variance with the prevalent custom of prescribing high-calorie diets in exophthalmic goitre. He points out that whereas some clinicians eliminate meat, practically all give a high-calorie diet with much cream. In his opinion, overfeeding a patient with a toxic goitre may cause harmful irritation of the already increased metabolism. He believes that the body worked more economically during the war, that a "sparing system" was automatically set up, and that the thyroid was probably the regulator of this automatic sparing sys-

tem. His interesting suggestions await confirmation or refutation.

ad 2. Practitioners of medicine have always been interested in their patients' constitutions, particularly in their bearings upon predisposition to disease. They repeatedly have occasion to observe that of three children exposed to measles two may sicken and one remain well; that one man deep in his cups may develop cirrhosis of the liver whereas another equally alcoholic may succumb to a peripheral neuritis and a Korsakow's psychosis; that the members of one family die at fifty of cardiovascular disease whereas those of a neighboring household, living under similar conditions, may attain to a venerable age. Thoughtful physicians and laymen have pondered these facts, but during the latter half of the nineteenth century, the attention of scientific medicine was concentrated almost solely upon the study of bacteria and other extraneous sources of disease—with extraordinarily fruitful results—while the study of the constitution was wholly neglected. Indeed, the term came in for some reproach as a cloak for ignorance and as lacking a scientific basis.

With the change in the trend of biological research from the study of the origin of species (evolution) in the preceding century to that of the origin of the individual (heredity and development) in the present century, a scientific basis for a constitutional pathology is becoming apparent, and it is to be expected that in the present generation of workers there will be a closer coordination between medical investigation and fundamental biological research. Biologists teach us that the general principles of heredity and development that have been and are being established through animal experiment are broadly applicable to man and may be used as foundations for medical studies. From those experiments we learn that the fully developed organism (phenotype), in this case the realized adult person, is the resultant of a long series of interactions between the zygote (the fertilized ovum, genotype, idiotype) and its environment; that the "determination factors" (ids, genes) of development are contained within the germ and that the "realization factors" of development lie in the environment; that both factors are necessary for development, which is, however, governed mainly by heredity.

Professor Conklin explains graphically by his figure of the shuffle and deal of the chromosomes the almost infinite possibilities of hereditary differences. Considerable variation in human beings is, of course, compatible with health, though each variation may be associated with some special predisposition to disease, and it is reasonable to believe that the study of such individual variants may lead to the development of special, as contrasted with general, prophylaxis. Such variants may manifest themselves by morpho-

logical distinctions, by physiological differences, by differences in the evolution or involution of development, etc.

Experimental studies upon the influence of endocrine products upon growth in early stages of the development of certain larvae and clinical observation of the effect of endocrinopathies upon the physical and mental development of human beings make it seem probable that, in the developmental processes of both normal and abnormal phenotypes, the internal secretions may play an important rôle. It seems possible, as Barker has said, that the genes, or determiners, of hereditary characters may, to some extent, at least, operate through the mediation of the endocrine glands in the production of varieties among phenotypes, including perhaps those pathological personal variants that fall victims to diseases the etiology of which seems at present quite obscure. It is certain that the rôle of the internal secretions must be strongly considered in any systematized study of the pathology of constitution. It has been pointed out that the diseases of the endocrine organs, especially those that develop insidiously and give rise to the classical endocrine syndromes, appear to be usually of endogenous rather than of exogenous origin, that is to say, they develop as the results of special anomalies of constitution. Endocrinopathies tend to run in families and perhaps the interrelationships between the glands may account for the fact that all the cases in one family need not be of the same general type. There are criteria by which one may recognize or suspect, for example, a thyreotoxic constitution, a hypothyroid constitution, a hypopituitary constitution or a hypogenital constitution, and in certain cases suitable prophylactic measures may be instituted. We may cite, as probably the most striking example, the hypothyroid state in which the definite clinical criteria and the basal metabolic rate furnish a reasonably satisfactory scientific basis and in which suitable prophylaxis may prevent or ameliorate distressing symptoms that might otherwise arise from any or from all the body systems.

Your attention may be further directed to the extensive prophylactic measures now being adopted for the prevention of simple goitre; to the report by Bramwell (1908) of the demonstration of recessive heredity in a glycosuric family; to Gossage's report of dominant heredity in a family exhibiting diabetes insipidus; and to the contribution by Lenz (1917) who cites evidence of a dominant, partial sex-limited heredity for the thyreotoxic constitution which he believes may account for the preponderance of incidence of exophthalmic goitre in females. These citations illustrate the growing interest of clinicians in the relationship between the endocrine organs and the pathology of constitution.

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BAIRD THE NATURALIST[1]

By Dr. C. HART MERRIAM

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A CENTURY ago to-day was born into the world a babe destined to develop and organize the natural sciences in America and to become the teacher and leader of the upcoming generation of naturalists—one whose modesty, simplicity, sincerity, industry and masterly accomplishments were to become an inspiration to fellow-workers.

The time was opportune. Coming into manhood at a period when our fauna was little known and the literature fragmentary and scattered; possessed of vigorous body, a clear intellect, sufficient ambition, and an unquenchable love for natural history, he early perceived the opportunity and need for original research and threw himself body and soul into the field.

Confronted with the unsatisfactory state of the best works on zoology, with special reference to the vertebrates, and with the incompleteness of museum collections, he saw at once the pressing need of gathering the raw materials, and became of necessity a collector of specimens—for without specimens how could he study and classify the birds, reptiles, batrachians, fishes and mammals in which he had already become so acutely interested.

He began at about the age of 15, the period of maximum youthful enthusiasm, and from that time until overwhelmed by the pressing duties of the assistant secretaryship of the Smithsonian in 1850 continued his search for specimens with ever-increasing eagerness. And one can not but be amazed at the magnitude and diversity of his collections.

It is a matter of record that when 27 years old he had accumulated 3,500 skins of birds, upwards of 500 glass jars and numerous barrels, kegs and tin vessels of reptiles, 600 skulls and skeletons of North American vertebrates, a number of embryos "in pickle," and large collections of fossil bones from the bone caves of Pennsylvania and Virginia.

This enormous collection when shipped to the Smithsonian in

[1] Abstract of address at the Centennial Anniversary of the birth of Spencer Fullerton Baird, held in the National Museum February 3, 1923. Two prominent sources of information have been freely drawn upon: Goode's "Bibliography of Baird," 1883; and Dall's "Biography of Baird," 1915, the latter containing a multitude of Baird's early letters and other important data.

October, 1850, filled two railway cars and became the nucleus of the National Museum.

Birds were his first love, followed closely by reptiles, and a little later by mammals and fishes, all of which continued to occupy his affections to the end of his life. Birds, mammals, reptiles and batrachians were the subjects of his most elaborate and important contributions to science. He began to publish descriptions of new species of birds in his 20th year, and a year later brought out an important faunal paper on the "Birds of the Carlisle region." In 1845 he published his only strictly botanical paper, treating of the trees and shrubs of the same region; followed in 1849 (when he was 26 years old) by a most important original "Revision of the North American tailed-batrachia," and soon after by "Descriptions of new salamanders," and a paper "On the Bone Caves of Pennsylvania," after which until near the end of his life his contributions, appearing at frequent intervals, covered a wide field.

Before the close of his 18th year, in order to acquaint himself with what had been written on the natural history of America, he had searched the public and private libraries of Harrisburg, Philadelphia and New York for volumes not available at Carlisle, and in 1846 had visited Boston and New Haven for the same purpose. It is known that he once—and inferentially several times—walked 40 miles to Harrisburg and back in a single day, carrying a load of borrowed books and bringing back fresh ones.

Baird as a young man was strong and well developed, more than 6 feet in height, broad shouldered and good looking. He was a famous walker, and on one of his excursions, though encumbered with gun and knapsack weighing 25 pounds, walked 400 miles in 21 days, and on the last day no less than 60 miles in 18 hours (walking time exactly 15 hours); and during the year walked upwards of 2,200 miles.

In November, 1841, he began studying medicine in New York under Dr. Goldsmith, but medicine proved not to his liking and he soon returned to Carlisle.

While he was in New York Dr. Goldsmith, who evidently was very fond of him, took him to see Audubon, with whom he had corresponded for several years. Other distinguished naturalists met in New York were George N. Lawrence, the eminent ornithologist, Titian R. Peale, of the Wilkes Expedition, James DeKay, author of the large volumes on the natural history of New York, J. P. Giraud, author of "The Birds of Long Island," and John G. Bell, the leading taxidermist of the time and later a companion of Audubon on the Upper Missouri expedition.

In 1842 he was urged by Audubon to accompany him on his

expedition up the Missouri River to the Yellowstone, but owing to the fears of his mother and other relatives, declined.

In 1845 Baird was appointed professor of natural history and curator of the cabinet in Dickinson College at Carlisle, Pennsylvania, without pay; the following year he was granted a salary of $400, which in 1847 was raised to $650, and in 1848 to $1,000. On beginning his work as teacher he instituted a series of outdoor excursions on Saturday afternoons in the course of which natural history collections were made. This was of great practical assistance to the students, and although in accordance with a widespread custom of to-day, was at the time "a startling innovation." (Lucy Baird, in Dall, p. 145, 1915.)

By this time Baird had mastered several foreign languages. In 1845 he was reading German and had begun Italian and Spanish, and early in 1847 he began Danish. In addition to readings for his own use he had done a large amount of translating, especially from German, for Audubon, Cassin and Dana. In 1848 he undertook the translating and editing, involving the rewriting of many of the chapters, of a very pretentious work—the "Iconographic Encyclopedia"—which appeared in installments, the first four numbers in 1849, the completed volumes in 1852.

Throughout the forties his frequent letters to his brother William teem with ornithological details, for during this period he was not only collecting birds most vigorously and had been given many rare species by Audubon, but also was exchanging specimens with both American and European ornithologists.

In January, 1847, acting on a suggestion from James D. Dana, Baird applied to Professor Joseph Henry, secretary of the newly established Smithsonian Institution, for the position of curator. But the funds of the institution available for science were at a low ebb, owing to large expenditures for the construction of the building, and it was not until July, 1850, that he was elected assistant secretary of the institution.

Then, when actually installed in this coveted position, his head bursting with the dream of a great national museum, his efforts to secure specimens were redoubled.

Again the time was opportune, for the government was just beginning its famous series of Pacific Railroad surveys, in the hope of finding a practical route from the Mississippi River to the Pacific.

Not only were these several expeditions equipped by Baird with collecting outfits, not only were one or more men on each instructed for the work, but in most cases the choice of the naturalist or surgeon-naturalist was delegated to him.

This was his golden opportunity, and he utilized it to the utmost,

calling on friends and correspondents at home and abroad, and setting in motion the ponderous machinery of the government—the army, the navy and the civilian branches—to aid in bringing in materials. His method was not that of the *official order* but of the *personal appeal.*

And when one finds among his devoted helpers such luminous names as those of Farragut, of the navy, and of Abert, Abbot, Emory, Ives, McClellan, Marcy, Simpson, Sitgreaves, Scott, Thomas, Whipple and Williamson, of the army, and of such surgeon naturalists as Drs. J. H. Clark, C. B. R. Kennerly, Wm. Gambel, J. S. Newberry, George Suckley and Samuel Woodhouse—one may perhaps realize something of the extent of his acquaintance, the keenness of his knowledge of men and the far-reaching persuasiveness of his personality.

The resulting inflow of specimens and new information, pouring in in ever-expanding proportions, was no less than overwhelming, involving a great increase in the correspondence, great labor in keeping collectors supplied with equipment, and—most important of all—necessitating an immediate preliminary examination of the collections, for field naturalists are impatient to learn the value of their contributions and must of course be encouraged.

But this was by no means all, for since at that time little was known of the natural history of the west, a large proportion of the species sent in proved new to science and had to be worked up and described; moreover, the reports of the field naturalists had to be corrected, edited and sometimes rewritten.

The whole country was alive to the importance of these transcontinental expeditions and eager for the results, so that prompt publication was a necessity. And Baird's share in the preparation of the resulting thirteen fat quarto volumes with their attractive maps and illustrations was enough to occupy an ordinary man a lifetime.

But Baird was no ordinary man.

He saw that the time had arrived for a complete overhauling and rewriting of the technical monographic works on the various groups that go to make up our terrestrial fauna, and was ready and eager for the opportunity. Realizing perhaps that he was the best qualified person in the world for the task, he accepted as his share the preparation of the volumes on birds, mammals and reptiles. Labor of this exacting kind demanded, but could not possibly receive, his entire time. His days were crowded with the pressing duties of his position at the Smithsonian, so that his scientific work had to be done at home and at night. Five years previously, in a letter to his friend George P. Marsh, he had spoken of working 12

hours a day in winter and 15 in summer, but during the rush and pressure of the Pacific Railroad reports these long hours were materially increased. And it is a matter of record that in the case of his renowned monographs of American mammals and birds, the text written one night frequently came back in proof the next, while at the same time new text had to be continually supplied, with no opportunity for the checking and revision of manuscript which most of us find so essential.

One can not but envy the reserve power and intellectual strength that enable a man to cope successfully with an emergency of this character.

Baird's great monographs set the clock of knowledge far ahead, laid a higher foundation for future research, and at once took their place among the classics of systematic zoology. Probably no works by a single author ever exerted so stimulating an influence on the naturalists of the time.

With the appearance of the volume on birds in 1858 began what the late Elliott Coues designated the "Bairdian period of American ornithology"—a period that continued for nearly 30 years "and was characterized by an activity of ornithological research and rapidity of advancement without a parallel in the history of science." And our colleague, Dr. Leonhard Stejneger, writing nearly 40 years ago, contrasted what he called the "Bairdian School" with the older "European School," pointing out that while the latter requires the investigator to accept an author's conclusions on the strength of his word alone, the Bairdian school furnishes the facts from which one may draw his own deductions.

Turning now to a later period (the early seventies) when Baird's major activities had been transferred from the land to the sea, a new impetus was given the study of aquatic life, and it came to pass that under his guidance the knowledge of marine faunas grew as had previously grown the knowledge of terrestrial faunas, until the living things of both the lands and the waters of North America came to be better known than those of any other part of of the world.

Baird was of the type that make the best naturalists. Beginning as a field collector and student of birds and soon expanding his interests to include reptiles, batrachians, fishes, fresh water mollusks, fossil shells, fossil bones, mammals and plants, he acquired a deep understanding of the fauna and flora of his home region, which in turn created a thirst for broader knowledge, leading to collecting trips in many states, to exchanges with many lands, to the bringing about of natural history explorations in the far west and far north, till his collections overflowed with representatives of the major part

of the vertebrate fauna of the continent. In his studies of this material he became the keenest, ablest and most authoritative of American writers on vertebrate zoology. No other person had ever combined in equal degree the qualities of the successful museum man with the high scientific attainments of the monographer of groups.

It was fortunate for him and for us that he lived in—if in truth he did not bring about—the period of greatest activity in the history of the development of the natural history sciences in our country.

We know the value of his personal contributions to systematic zoology, but we may never know the extent to which the progress and dignity of science in America are due to his influence and wisdom, especially in his relations with influential government officials during the 38 years of his service in the Smithsonian Institution and Fish Commission.

Nor can we measure the results of his encouragement and helpfulness in shaping the careers of the younger naturalists, some of whom, no longer young, are present this evening. For no matter how busy—and he always was overwhelmed with work—Baird never begrudged the time given to the encouragement of young men who were really in earnest. Most American naturalists of the generation now all too rapidly drawing to a close owe to him at least a part of their training and much of their success, and realize how great a privilege it was to have been enrolled under his leadership.

On an occasion of this kind one may be forgiven an indulgence in personal reminiscences. I, in common with perhaps two or three other naturalists here present to-night, owe to Baird much of whatever we may have accomplished, particularly with reference to his advice and assistance in shaping the early part of our careers.

It was Baird who, 52 or 53 years ago, asked me if I would like to go West on one of the government expeditions, in reply to which I confided to him that such was the ambition of my life; and a year or two later (in March, 1872) he notified me that I had been appointed naturalist of the Hayden survey of the territories, in the course of which it was my privilege to visit the far west and make collections of mammals and birds in the little known territories of Utah, Idaho, Wyoming and Montana.

After my return it was Baird who gave me every facility for work in the Smithsonian building, and in the spring suggested a collecting trip to Florida, which I made early in 1873. This was in part an offset, for Baird knew that I had set my heart on accepting a position on the Wheeler Expedition, to which my friend

Henry W. Henshaw had been attached the previous year. Baird had dissuaded me from going, insisting that if I went I would probably continue to go year after year and remain a *collector* of natural history specimens rather than become a trained naturalist. Instead, he urged me to go to the Sheffield Scientific School of Yale, where I would have the advantage of laboratory work and lectures on zoology under Verrill, and in botany under Eaton. His advice, in which my father concurred, was followed, and in 1875, while I was still at Yale, he appointed me an assistant in the invertebrate laboratory of the U. S. Fish Commission at Woods Hole. Here, by a fortunate combination of circumstances, Samuel F. Clarke (later professor of zoology in Williams College) and I were put in charge of much of the season's work with dredge and trawl on the steamer *Blue Light,* and in the laboratory had the privilege of working alongside of Alpheus Hyatt, Sidney I. Smith and Tarleton H. Bean.

A year or two later it was the combined influence of Baird and Verrill that prompted me to draw out from the Utica Savings Bank all the money I had in the world in order to make a collecting trip for rare invertebrates in the Bay of Fundy, taking with me Edmund B. Wilson, then a boy, now DaCosta professor of biology in Columbia University.

Again it was Baird who induced me to collect fishes in the Adirondack region of northern New York and provided part of the necessary outfit. Still later it was with his cooperation that I visited the Newfoundland and Labrador seal fishery as surgeon on the sealing steamer *Proteus.* And finally, it was his influence more than that of any other one person that induced Congress to make the initial appropriation for ornithological work in the Department of Agriculture, beginning July 1, 1885, which later developed into the present Biological Survey.

Those of us who were closely associated with Baird are sure to recall many acts of thoughtful kindness. One of these occurred during the winter of 1872–73 when G. Brown Goode and I were working in the basement labyrinths of the Smithsonian. Suddenly, to our astonishment and joy, Professor Baird appeared, bringing the renowned Louis Agassiz down "to see what we were about!" Here, standing beside us, were the two greatest living naturalists; the two who had done most to encourage young men and to advance the study of natural history in America—the two men in all the world upon whom we looked with greatest reverence.

In natural history, as elsewhere, there are guideposts to direct the steps of the explorer. Some of these in America—pillars rising conspicuously from the broad plain of knowledge—were Audubon,

Agassiz, Baird. Sir John Richardson deserves a place among them, but his researches were restricted to the far north.

Audubon was the pioneer, and while his personal labors were in the fields of ornithology and mammalogy, the genius of his writings and the magnificence of his paintings did much to arouse general interest in the natural history sciences.

Agassiz combined two quite distinct qualities—those of the patient investigator and the popular lecturer, and with his genial manner and pleasing address, did more than any other man, before or since, to popularize the study of natural history.

Baird, on the other hand, while a wise councilor and a born organizer and leader, was personally so modest and shy that he never appeared on a public platform; a man of tireless energy, an enthusiastic collector, a critical student, and able delineator of the characters of animals, the best informed man in the world on the vertebrate faunas of North America, he became, as summarized by the Encyclopedia Britannica, "the most representative general man of science in America."

That it should fall to the lot of one man to rise to the highest eminence in science as a result of the value of his own contributions, and that this man should be chosen to occupy the highest position in the gift of science, is not in itself so strange; but that the personality and influence of this same man should prove so stimulating and far-reaching as to create an army of enthusiastic workers in the various fields of natural history, that it should enlist in behalf of his projects a multitude of civilians and high officials of the government, and that it should move the Congress of the United States to do his bidding, is a thing unprecedented in the history of science.

BUSINESS STRATEGY IN NATIONAL AND INTERNATIONAL POLICY[1]

By Dr. JOHN F. CROWELL

STRATEGY is another term for planning. The planning implied in the military use of this word has attained a degree of scientific thoroughness which might well be applied to the peaceful pursuits of commerce and industry. It should not, however, be assumed, as is sometimes done mistakenly, that commerce is war. Commerce is peace, because it is service—service mutually beneficial to both the seller and the buyer. Each party to the commercial transaction has added to his wealth by the exchange, whether it be money for goods or goods for goods, as in barter.

The world market is the field of service within which commerce and industry engage in their ministration of increasing one another's wealth and welfare. Let us, therefore, discard at the start the cutthroat conception of commerce and industry as abnormal in considering the application of the principles of strategy to business enterprises. We are justified in making this plea because the *morale* of economic life has made gains in many directions within comparatively recent years. The brutal instincts of commercial highwaymanship have lost caste in favor of the serviceable ministry of mutually beneficial salesmanship.

From this viewpoint let us consider what is involved in the strategic organization and operation of a business enterprise whose field is the local market, the regional market, the domestic or national market or even the world market. For the scientific principles of mercantile and industrial strategy are applicable to units of any size. They are equally applicable to the manufacturing or industrial unit of enterprise and to the commercial organization engaged in mercantile distribution. Nowadays so many of the manufacturing industries engage in direct selling of their products as to make it necessary for them to be salesmen as well as industrialists. In fact, manufacturing which is always producing for a market is never safe without taking the selling capacity of its products on their inherent merits into account. Planning systematically involves both making and merchandising as complemental parts of the same economic process.

[1] Address delivered at the Cincinnati meeting of the American Association for the Advancement of Science, before the Section on Social and Economic Sciences, December 28, 1923.

I. The Four Principles of Strategy

Business strategy is long-term planning based on scientific surveys of the field and its essential factors. Systematic planning in economic enterprises makes it essential to seize upon the main factors at once. He who can not draw a clear line of cleavage between the essential and incidental in a situation has no business in the field of strategic planning. Likewise, to insight must be added the aptitude of foresight. To foresight and insight add hindsight. Hindsight is another name for history. He who would plan strategically a campaign for a locomotive manufacturing industry for the home or the foreign markets without knowing something of the main points in the history of locomotive selling at home and abroad would simply be another case of the half-blind leading the blind. It might be better than nothing, but it is not the best that can be done. The same applies to any other industry, any mercantile house, and to transportation systems or any banking concern. They all need strategy to realize their possibilities. Their success is measured by the strategic capacity of the personnel on whom management devolves.

(1) *The Principle of Position.* The first principle of business strategy is to ascertain in the fullest practical manner the actual position of an enterprise which is to be made the subject or basis of this systematic planning. If it be a manufacturing plant, which has grown up locally, for example, and has come into the hands of people who believe that it has a larger destiny than the local market, it must then be ascertained as to whether that class of industry is of the kind which ever gets beyond a given radius. An iron foundry, for example, produces products of such bulk in weight as to limit its market to a very definite radius of transportation costs. Silk products, on the other hand, are subject to no such condition. You may, however, have a chain of iron foundries reaching around the globe. But in either case the facts of position with reference to marketability lie at the bottom of strategic planning. The nature of the product is therefore the first strategic element in defining its actual position. Once defined, it helps to settle other questions in the same field.

The principle of position calls for a second fact in the form of the competitive relation of the product. Has it a field of its own, so that it need not divide the market with one, two or ten competitors? The basic factor in competition is costs. A Paterson silk manufacturer worked for five years in the improvement of his manufacturing processes to a point at which he felt confident that he could operate profitably when every other competitor had closed his mill. In due time, the silk trade said of his establishment that

it was the only one that was making money. This illustrates the fact that strategy begins, or at least is vitally centered, at the factory. Competitiveness of a product covers a much wider field than what has here been designated. It includes financial position, both actual and potential. It likewise embraces selling capacity. In fact, the whole content of the manufacturing plant's experience has to be laid on the table to show what sort of a hand the player has with which to win his game.

Strategic position involves geographical re-location, if necessary, for a contemplated campaign. An ocean-going shipbuilding establishment should not be located on any of our great rivers or on the great lakes except it be near the mouths of rivers with short and direct access to the sea. These things are self-evident. Such is the Delaware shipbuilding area—our leading district of the kind. It is not however so apparent where a plant should be located which manufactures both for the domestic and the foreign market. Take automobiles, in which we lead the world's exporters. The planning of one of the largest of these manufacturers has resulted in shifting the export division of the industry across the border into Canada, primarily for two purposes: (a) To avoid retaliatory treatments of his products in foreign countries; (b) the desire to profit by the imperial preference duties on foreign imports into the United Kingdom of Great Britain, her dominions, her colonies and her other dependencies.

From this it is evident that the worldwide market imposes certain conditions on the location of industries which aspire to a place on the map of the world. It is also evident that the type of man needed for salesmanager is not one of the swivel-chair, single-track minded type, but rather a man with a head capable of entertaining a competent grasp of international economics.

II. The Principle of Communications

Business strategy involves the careful study of the lines of communication and transportation from two points of view: first, where and how to get the commodities or the raw materials and the manpower necessary for the progressive development of the business. For with the expansion of markets there will come constantly widening demand for output to meet the multiplying customers. Therefore, the question of access to the markets for labor and materials is vital. Not a few industries whose success was achieved in districts where anthracite fuel was once available have found it necessary to move within the radius in which more economic fueling could be insured, whether from bituminous coal, from coke, from water power or from hydro-electric sources of supply.

Such was the Lackawanna Steel Plant which moved from Scranton to Buffalo, in order to gain the advantage of low-cost transportation on iron ore and on fuel, the former coming down the lakes from the Minnesota orebeds.

The second viewpoint from which communication must be considered as a factor in strategic planning is that of transportation to markets. Is it better to have a plant at the seaboard to manufacture both for the populous districts in the home market and for the export trade? Something depends on whether the market is to be of continental or of universal scope. If you seek to serve European markets and Mediterranean countries, then the North Atlantic coast has several good outlets. Avoid a port whose traffic facilities are congested a good deal of the time under existing conditions of traffic management. An uncoordinated system of putting streams of merchandise for export through the neck of a choked-up bottle is rank folly.

On this question of selecting the export gateway through which one's shipments to foreign markets should move, the western flour manufacturers, by means of the through bill of lading, and special arrangements with the port authorities of Philadelphia have special piers through which they get the most direct movements between the mills at home and the importing merchants abroad. Baltimore likewise and also Boston command export products throughout the interior traffic areas with which they have good connections. Of these any manufacturer can avail himself. But it is necessary that he should know the strategic relation of his rail-and-water connection between himself and his market as a means of saving in the cost of distribution.

This second principle of communication applies to importing as well as exporting. The properly equipped department store which imports porcelain goods from an Austrian factory is not master of the situation strategically unless its traffic manager knows the more advantageous routes of shipment, whether by rail inland to the Mediterranean or north to the Atlantic for ocean transport to the United States by way of the port which is most economical in its treatment of hinterland goods.

Something should be said of the industry or the mercantile house which serves only the domestic market. Some of the large retailing, wholesaling and jobbing centers of the country are more advantageously situated than others. But few of them have looked thoroughly into the question of such combination of shipping rates, by water and rail, as will enable them to reach the same markets at lower costs or newer markets at costs which admit of profits. Here is a field for the traffic specialist in cooperation with the

traveling salesman under the same salesmanager. A compilation of the facts is a clerical task. The proper use of them requires strategic talent. Without such data, developing markets is a speculation; with such data rationally utilized the expansion of markets becomes a science of merchandising.

III. The Principle of Adequate Resources

In planning a campaign strategically time is an element. A plan which peters out for lack of resources in two years but which might well have won out if there had been enough resources for carrying on during a period of four years is manifestly an evidence of bad generalship. The plan of campaign for any enterprise must first lay down the size of its problem. We intend to put our fabrics, or our patent food, into the West Indian and Caribbean territory by building a well-established sales organization so as to cover every essential point or community. How long it will take is secondary to the question of what amount of resources will be needed (a) in the equipment of the home base, (b) in the sales organization to be maintained and (c) in the incidental expenses in personnel and capital for changes in condition and meeting extraordinary events.

This latter point may be illustrated by the collapse of prices and the utter breakdown of credit relations which occurred in the years 1920 and 1921 in American trade relations with South and Central American as well as West Indian markets. In this case, resources were found to be wholly inadequate, as measured by reserves set aside for emergency conditions. It was a wise employer who when engaging a salesmanager put as a final test to the applicant, "How many commercial and financial panics have you been through?" For a salesmanager who has never weathered a panic is after all but a fair weather captain. Many of us may be too young to have passed through this scope of experience; but there are thousands of business men living who can be interviewed on their experiences, and there are hundreds of books and published official documents full of information. Annual reports of corporations publish valuable information. So that there is no possible excuse for the export manager to live in ignorance of conditions that at any hour may engulf him and his business for want of ordinary foresight.

IV. The Fourth Principle: the Selection of the Objective

This principle gathers into its scope lines that reach out from the other three. In business strategy the selection of the objective

is really the first and foremost of basic factors involved in industrial and commercial planning. This includes the following elements:

(1) What is it that is to be manufactured or marketed?

(2) What is the actual production and the extent of competition in the commercial distribution of the specialty in question?

(3) If the market hitherto has been only regional or domestic, that is, national in scope, would it be good business policy to extend the market into other continents, unit by unit, and could the manufacturing capacity be expanded to meet such a program?

(4) If international expansion by continental units were deemed desirable, what system, systems and methods of export merchandising could most advantageously be used in selling abroad from the home manufacturing base?

(5) If surveys and research into these conditions and problems were found to justify going ahead on the lines indicated, from what sources could adequate financing be provided for say a ten-year program of expansion?

(6) Where and how could a competent personnel be found or developed to meet the gradual or rapidly enlarging scope of business involved in this program?

All the above lie within the scope of determination of the business objective before a single step is taken in any other problem. The answers to these questions will leave little that is necessary for future inquiry within this principle. But having determined these facts properly, the ascertainment of data embraced in the other three principles will be much simplified.

V. Business Strategy the Key to Post War Reorganization

Scientific business planning, in which traditional sentiment, business nepotism and political meddling of all kinds are subordinated to the problem of permanent reorganization of industry and trade, is really the next great step in the national evolution of our business institutions and in their better adaptation to world-wide service. Some of our best concerns have already taken this step and are prepared for business in any part of the world market, near home or in far Cathay. But the vast majority have been half asleep on the comfortable berths which they sought to make for themselves in the transitional readjustment following the war. Thousands of enterprises have thus built on the sandy foundation of inflated values and other follies of business self-deception. It is nothing short of the falsification of fact to say that there has been an honest, enlightening and thorough-going reorganization of business since 1920 and 1921. On the contrary, as every official in the

Internal Revenue Office at Washington knows and every accountant who has had to do with the income tax should know, too many people in the manufacturing and commercial, the financial and the transportation worlds have been preoccupied in the task of belittling the taxable content of their business assets. If the business world had devoted an equal amount of attention to an honest-to-goodness reorganization of business, instead of covering up weak spots, decayed branches and otherwise unhealthy symptoms, the business world as a whole in the United States would not be headed, as some are now convinced it is, towards its day of reckoning with over-inflated values.

VI. Is Commerce Overloaded with Personnel?

I raise another question whether we are not building up a badly balanced economic organization in our national life by overloading our distributive machinery, including commercial and financial organization, railroads and shipping, as well as the administrative functions of government, with far more people than can be productively employed; while, on the other hand, we are draining away from the tillage of the soil, from the working of the mine and in thousands of places from the smaller industries of towns and villages the labor which is paid approximately by the value of what it produces.

General Francis A. Walker, one of the foremost American economists, many years ago called attention to this tendency in American economic life on the part of the distributive organizations to overgrow their normal capacity and become crowded with manpower at the expense of the extractive and manufacturing industries. Nowadays manufacturers are merchandisers as well. Have we not again reached such a stage of development in which the distributive and some of our manufacturing organizations have competed unduly for the labor supply and thus created a situation of uneconomical production costs with regard to the consuming world?

The answer is that not a few manufacturing establishments typical of conditions in the textile and the electrical industries have gone on making goods and piling up stocks at a cost basis which is forcing them out of touch with what the consuming world is willing to pay for them. If the truth were known, there are more of these than it is well for the country to have when everything but farm products generally is at an unhealthily high price level.

Whether the existing gap between manufacturing costs and consumers' purchasing power is likely to widen or close up remains to be seen. But this situation is one of the big problems of domestic

industry. Nor is it confined to the home market. If its existence is to be more or less removable, the best of business generalship on the part of our leaders, including bankers, manufacturers and merchants, will be necessary. In other words, when you are rebuilding a bridge on a railway line, displacing an unsound wooden one by a more effective steel bridge, you need the best kind of engineering talent to prevent trouble.

VII. The Great Unsolved Commercial Enigma

The position of the United States as a unit in world commerce presents at this time one of the most important problems which has ever confronted us in our international relationships. Our home market is prosperous, partly by reason of its great scope and unmatched volume of popular purchasing power. But we are now a surplus exporting country whose agriculture has already felt the damaging effects of unfavorable foreign markets. The world market is the price determinant for staple agricultural products. As for cotton, thanks to the boll weevil, the world market price is all that could be desired, but for grains and meats, the outside world is underselling us. If this is to become permanent our scale of production must do one of two things. It must either adapt its production to the protected home market or it must find ways and means by which to market its surpluses profitably in the world market. Such a readjustment is more than incidental—it is fundamental and far-reaching as a policy in its effect upon our social and economic life.

The great unsolved problem, therefore, consists in the adjustment of the home market built up and maintained on a price level out of line with the prevailing price levels and purchasing power of the non-American world. We are at the crossroads of commercial destiny. Shall we adjust the home market to the world market, or shall we rack our brains to fortify ourselves by devising new methods for a more intensive and complete national isolation?

VIII. A Task for Business Generalship

If our home affairs as such need attention, rather than our outer relations, what, then, is the real task of business generalship in the existing economic situation? What we need most is a searching examination, industry by industry, trade by trade, into every organic division of our national life, such inquiry to be based on scientific surveys of the structure and functions of each such division. Such a survey has recently been made into the coal industry, and we are getting at the facts of the false situation resulting from the deadlocking of the industry in restraint of trade.

The business strategist is rapidly taking the place of the captain of industry, especially in large scale industrial and commercial enterprises. The old-type industrial captain has not had the breadth of vision nor the grasp on tendencies old and new to survive. Strategy, according to this exposition, means business planning based on scientific surveys of a concern's objectives, resources, connections and internal conditions. The captain of industry is gone or has gone, and in his place are found divided responsibilities among at least three divisional leaders—the salesmanager, the cost accountant and the financier. The specialist has captured the captain's stronghold and the strategist has become the general in chief. Normally headship of business seems to be passing into the hands of a central executive committee functioning really as a Board of Strategy. The logical head of that board is a chairman graduated from the position of president at divisional counsels where the details of practical operation had occupied his attention. As chairman of the board of strategy questions of principles and policies occupy his entire thought and effort, leaving details and specialization to the divisional leadership further down.

The application of the principles of economic and social science to surveys of markets, sources of raw material, processes of specialization, methods of commercial distribution, warehousing, insurance and financing as well as shipping and transporting, if carried out in the hands of competent strategic talent, should put us in position to compete with the world in all lines in which we are entitled to succeed.

PAINTING THE TOWN RED[1]

By Professor T. F. CRANE

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THE first example noted in the New English Dictionary is: 1884, Boston, Mass., *Journal,* 20 Nov. "Whenever there was any excitement or anybody got particularly loud, they always said somebody was 'painting the town red.'" Two other examples are: 1897, *Chicago Advance,* 15 July, "The boys painted the town (New York) red with firecrackers (on Independence Day)": 1900, Capt. M. H. Hayes, *Among Horses in Russia,* London, I, 36, "I have found them in no way inclined to paint town and country red on the slightest provocation."

In the *Century Magazine,* vol. 36 (1888), p. 838, in an article "Frontier types," the writer says: "All this is mere horseplay, it is the cowboy method of 'painting the town red' as an interlude in his harsh, monotonous life." The expression is faintly criticized in *The Nation,* Feb. 1, 1906, p. 105, in a review of Rev. T. H. Passmore's "In Further Ardenne," London, 1905, "We may have no reverence for Louis XIV, but our feeling finds imperfect reflection in the description 'painting the closing decades of the seventeenth century red.'"

The *Literary Digest,* March 24, 1906, quotes from a review in the London *Times* by Mr. Walkley of Mr. Stephen Phillips's *Nero*: "Its hero is Nero, the esthete, the 'artist in omnipotence,' who uses human gore for his pigment and for his canvas the world. To speak more colloquially, he is the debauchee who paints the town red, not for the sake of debauch, but to gratify his taste for vivid color."

In *Notes and Queries,* viii series, vol. iii, p. 126, 1893, there is an amusing note: "Slang: 'Paint the town red':—'I say,' suggested George, 'I have finished my book and you have nothing to do. Let us pack up our traps and go to Paris and paint the town a vivid scarlet.' 'What?' asked Jonah Wood, to whom slang had always been a mystery. 'Paint the town red,' repeated George, 'In short,

[1] I was quite surprised to read in so serious a journal as *The Times Literary Supplement* for October 25, 1923, the following use of a slang expression generally regarded as of American origin. "It required all the strength and wisdom of Lord Salisbury to stave off the dangers into which we were rapidly rushing at the time when it appeared to be the ambition of the nation to paint the whole world red." It has occurred to me that a study of the expression and its possible origin might be of interest at this time. The materials for this paper were collected some years ago, but the article has never been published.

have a spree, a lark, a jollification, you and I.'" "The Three Fates," by Marion Crawford, 1892, p. 386. The writer of the note then continues: "To paint the town red seems generally to be considered modern slang from America; but if Jonah Wood had known his Shakespeare he might have got some light by recalling Prince Henry's narrative of his friendship with the leash of drawers, of whom he says: 'They call drinking deep, dying scarlet' (*I Henry IV*, ii, iv). Is there anything modern Shakespeare did not anticipate?"

I have not time now to multiply examples and it is not necessary for my present purpose, but I can not refrain from citing a curious book which shows the spread of our expression, and, incidentally, the remarkable way in which the Germans and their kin the Dutch find material for their dissertations and monographs. The book in question is "Studies in English, written and spoken, for the use of continental students, by C. Stoffel, Zutphen, 1894." Pp. 170–272 contain an article, "Annotated specimens of ' 'Arryese,' a study in slang and its congeners." The article is based on letters in verse which appeared in *Punch* in 1877 and later. Mr. Stoffel says, p. 222, "What in Dutch is vulgarly called 'den boel (de peentjes) opschleppen,' is in the 'Arry dialect known as 'painting the town red,' equivalent to, being on the spree, out larking," etc. *Punch*, Jan. 24, 1885, "Christmas is over and gone in every sense, for we have all been half-seas-over, and all our money is gone. . . . We have painted the town red and no mistake"; *Judy*, Oct. 20, 1886: "Something to re-arrange his nervous system as he was busy painting the town red last night"; *Punch*, June 4, 1887: "To climb up a lamp-post and paint the town red"; *Punch*, June 25, 1887 ('Arry on the Jubilee): "The town's painted red, I can tell you, a regular flare-up and no kid"; *Punch*, same date ("A Baboo's attempt to write a jubilee ode"): "For we greet the fiftieth recurrence—Of the day our Queen the throne ascended—With a solemn universal high jinks—Painting the town red"; *Judy*, March 14, 1888: "Spenser turned up from Ireland and Walter Raleigh, and he and I painted the town red like R. A.'s"; *Punch*, May 7, 1892 ('Arry on Wheels): "My form (at bicycling) is chin close on the 'andle, my 'at set well back on my 'ed,—And my spine fairly 'umped to it, Charlie, and then carn't I paint the town red?" The author of the article is careful to say in regard to the last quotation, "The phrase has paled down to the more general sense of 'enjoying oneself,' or, perhaps, 'astonishing the natives.'"

I leave to some graduate student in English, in search of a dissertation subject, the further study of our expression, and turn to the question of the origin and development of what is now a piece

of slang. It is evident at once that the discussion involves the use of the color red as expressive of festivity. The subject is an enormous one and includes such topics as: magic, fetishism, taboo, savage customs and primitive religions—in fact, almost every field of folklore. I must in my brief space confine myself to narrower limits, and I shall try to study chiefly the use of red paint on festal occasions, although I can not avoid touching on some of the other uses of red color, as well as the origins of such uses. I shall not observe a chronological order, but sometimes work backward from a given custom.

I shall begin with the instance which led me to prepare this paper. Cicero, in a jocose letter to L. Papirius Paetus (*Fam.* ix, 16), says, "What's all this about a pilot-fish, a *denarius* (a dinner for a quarter a head), and a dish of salt fish and cheese? In my old easy-going days I put up with that sort of thing; but times are changed. . . . Yet, after all, I don't require dinners superfluous in quantity; only let what there is be first-rate in quality and recherché. . . . But if you persist in bringing me back to a dinner like your mother's, I should put up with that also. For I should like to see the man who had the face to put on the table for me what you describe, or even a polypus—looking as red as Iupiter Miniatus." That is, as red as the statue of Jupiter painted with red-lead or cinnabar.

Pliny, *Nat. Hist.*, Bk. xxxiii, cap. 36, tells us: "It is also in silver-mines that *minium* is found, a pigment held at the present day in very high estimation; and by the Romans in former times used for sacred purposes as well. Verrius enumerates certain authors, upon whose testimony we find it satisfactorily established that it was the custom upon festivals to color the face of the statue of Jupiter even with *minium*, as well as the bodies of triumphant generals; and that it was in this guise that Camillus celebrated his triumph. We find, too, that it is through the same religious motives that it is employed at the present day for coloring the unguents used at triumphal banquets, and that it is the first duty of the censors to make a contract for painting the statue with this color. For my own part," he continues, "I am quite at a loss for the origin of this usage; but it is a well-known fact that at the present day even, *minium* is in great esteem with the nations of Aethiopia, their nobles being in the habit of staining the body all over with it, and this being the color appropriated to the statues of their gods."

In a later chapter (xxxv, 44), Pliny speaks of a clay figure of Jupiter in the Capitol and says that "hence arose the custom of painting it with *minium*." How long this custom lasted I do not know, but a Christian writer of the fourth century, Arnobius

(*Adversus Nationes*, vi, 10), speaks of seeing among the gods of the Romans "those with the savage face of a lion smeared with pure *minium*." Middleton, "The Remains of Ancient Rome," I, p. 360, says the custom lasted as late as the Imperial period.

I can not dwell longer now on this particular point, but will refer my readers to J. G. Frazer's translation of "Pausanias's Description of Greece," vol. III, pp. 20–22, where other instances are given and many examples of the use of red or blood among savages.

References to this custom are found in Latin literature, as those will recall who are familiar with their Virgil and Tibullus. In the sixth Eclogue, "Silenus," two young fauns, Chromis and Mnasyllus, find Silenus sleeping in a cave, and with the assistance of the nymph Aegle extract from him a song that he has often promised them: "Falling on him, for often the old man had mocked them both with expectations of a song, they fetter him in his own garlands. Aegle joins company and reinforces their faint courage. Aegle fairest of the Naiads; and now that his eyes are open, stains his brow and temples with blood-red mulberries." Servius, the ancient commentator, says: "On account of this expression many think that red is the color of the gods, whence triumphing generals have their faces painted red and Jupiter in his chariot in the Capitol." In the tenth Eclogue, "Gallus," the friend of Virgil, is portrayed lying under a mountain rock, lost in tears and despair, while his sheep stand mournfully around him. He is visited by the shepherds, as also by Apollo, Pan and Silvanus, rustic deities, who endeavor to console him, but in vain. In the 26th verse, the poet says: "Pan god of Arcady came, whom our eyes have seen, red with blood-stained elder-berries, and vermilion." Servius says on this passage: "Pan has his face painted red on account of his likeness to the ether, the ether is Iuppiter. Whence the triumphing generals, who have all the insignia of Iuppiter, the sceptre, the palm-branches"—as Juvenal says, x, 38, in tunica Iovis—"have their faces also painted red, like the color of the ether."

The two references in Tibullus are in the first elegies of the first and second books. In one the poet depicts the charms of country life; in the other he describes the old Roman festival of the Ambarvalia. In the former he invokes various rural deities and declares "that Priapus, the ruddy guardian of the orchard, shall be placed where he can terrify away the birds by his fierce sickle"; in the second passage, in describing the festival, he says: "The husbandman, wearied with the continual labors of the plough, first sang rustic words in determinate measure, and first modulated after his repasts, on the dry oaten pipe, the airs he prepared to sing before

the adorned images of the gods. The husbandman with cheeks reddened with *minium* first led thy unfashioned chorus, O Bacchus; a he-goat, the leader of the flock, was given to him from the full fold —a notable reward."

Whence the above mentioned customs, and why is red used as the color of festivity? It is generally conceded that the first red color was blood, and that all the festive and ceremonial uses of red are to be referred to the various meanings attached to blood, and that in the course of time, largely owing to the question of cost, red paint was substituted for blood. Instead of confusing my readers with a great mass of citations, the vice of Frazer, I shall quote almost entirely from a single remarkable article by Friedrich von Duhn entitled "Rot und Tot" in the *Archiv für Religionswissenschaft*, vol. ix (1906), pp. 1–24.[2]

Von Duhn begins with the contrast in German proverbs between "red" and "death," and "red" and "black." "What is red must become black and dead, and what is black and dead has the longing to become red again." In these characteristics of primitive thought lies in a nut-shell the key to the whole funeral ritual. In the countries around the Mediterranean the receptacles for the dead are painted red on the inside, and always with cinnabar or *minium*, like the color of blood. Everywhere the effort is made to arrange the passage of the dead into the other world in as little painful a manner as possible, by making the form and contents of the grave such as to give the idea that he is in his customary surroundings. This feeling is strengthened by regular offerings and libations at the grave, and the illusion is carried still further by painting the walls of his narrow dwelling with the color, and in a certain sense, the matter of life. All this was done not from piety, sympathy or sentimentality, but to make the dead as little harmful as possible to the living, so that he shall not want to return and carry others back with him. It was this fear of the return of the dead that led to mechanical means of prevention, such as the position of the body, heavy load of earth or stones on the grave, or strong receptacles or constructions with heavy stone at entrance. Sometimes the body was mutilated—eaten—burned.

As long as the decomposition of the body was not an accomplished fact, the notion prevailed that it still possessed sensation, either inherent or that might be aroused by certain means. The dead during this period longs instinctively for life, for blood; hence the offerings for the dead with all their endlessly diversified forms

[2] Another admirable article is by Hans Berkusky, "Zur Symbolik der Farben," in *Zeitschrift des Vereins für Volkskunde*, XXIII (1913), pp. 146–163; (Black, White), 250–265; (Red, 250–262). See Appendix B for résumé.

of accomplishment. Hence, at least as an ultimate reason, the red color in the inward arrangement of the grave. Even in the preparation of the body the use of red color was often indispensable. Servius (iii, 67, cf. Diels, *Sibyll. Bl.* 72) quotes an interesting passage from Varro, who says: "Women at funerals are wont to scratch their faces so that they may propitiate the gods of the under world by the sight of their blood. Whence also has been ordained the sacrifice of victims at the grave. Among the ancients even human beings were slain, but since it was costly and cruel to slay men, the custom arose of throwing over the dead a red garment."[3]

May I digress a moment here to call attention to an extraordinary survival of this custom? Before the coffin of the late Pope Leo XIIIth was closed forever, to await in a side chapel of St. Peter's his translation to the Lateran, a thin covering of crimson silk was spread over the body, which rested in a coffin lined with crimson velvet (A. Sonny, "Rote Farbe im Totenkult," *Archiv für Religionswiss.* IX, pp. 525–529).[4]

To return to classical times: the Trojans (*Aen.* vi, 221) cover the body of Misenus on his bier with his well-known red robes. "Purpureasque super vestes, velamina nota, Cojiciunt." So with Priscilla (Statius, *Silvae*, v, i, 221): "High upon a silken bier she lay, underneath a canopy of Tyrian purple." So Iphigenia was led to sacrifice in a red garment, and in India red is regarded as the color of death.[5] See also *Archiv. f. R.* xi, 406, O. Janiewitsch[6] for curious survival.

[3] Women were forbidden in the XII Tables to scratch their faces at funerals: Mulieres genas ne radunto, neve lessum (exclamations of sorrow) funeris ergo habento, Wordsworth, "Fragments of Early Latin," p. 535. Cutting of the flesh and hair was a common form of mourning, especially in the East. As connected with the worship of Adonis and otherwise leading to excess and fanaticism, it was forbidden in the Mosaic Law (Levit. xix: 27, 28, etc.), but in later times it seems to have been reintroduced. See Jeremiah xvi: 6, 7. Similarly this and other such prohibitions were not observed with any strictness at Rome. *Cf.* Propertius, III, 13, 27:

> Tu vero nudum pectus lacerata sequeris,
> Nec fueris nomen lassa vocare meum.

See passage from Servius cited above.

[4] Atlay in his Victorian Chancellors, I, p. 263, cites from Lord Brougham's Life, II, 428, an account of the funeral of Queen Caroline, wife of George IV.: "The crimson coffin slowly descended from the pier, and the barge that convoyed it bore the flag of England floating over 'Caroline of Brunswick, the murdered Queen of England,' the inscription directed by herself."

[5] To the passages just cited may be added: Statius, ii, i, 159, "The grim pyre (of Glaucias) was heaped upon a mound covered with scarlet flowers ('purpureo tristis rogus aggere crevit' "); *Thebiad*, vi, 62, "Tyrioque attollitur ostro molle supercilium." See also in Cicero, *De legg.*, ii, 59, in a corrupt copy of the XII. Tables, "extenuato igitur sumptu tribus reciniis et (tunicula?)

I can give but a single example from savage customs. In New Zealand the remains of the chiefs are wrapped in a red cloth, placed in a coffin stained red and laid in a grave painted red, near which a red grave-stone must be erected.[7] (*Cf.* Lubbock, "Early Races of Scotland," II, 462: "Origin of Civilization," p. 309.) See Appendix A.

In many graves little pots of rouge have been found as well as sepulchral images painted red, and Von Duhn is inclined to think this indicates an effort to give the dead the appearance of life and vigor. This, he thinks, is the reason why in all parts of Europe are found remains of the dead painted red. This is accounted for in a different way by A. Sonny in the article in the *Archiv für Religionswissenschaft,* ix, 525; he thinks that the red matter found in graves is the remains of offerings to the dead, and that paint was a substitute for the more costly blood of the sacrifice. It is possible, he thinks, that the custom later extended to the painting of the bodies red, and the bones from which the flesh had been stripped.[8]

It is a short step from the uses of red mentioned above to those in connection with religious ceremonies and festivities. The liturgical use of red is an interesting subject, but one I can not dwell on now. Those who have seen a great church at home or abroad decorated for a festival will remember the profound effect produced by the crimson hangings covering the stately columns of the edifice.

I have not found many references to the academic use of red besides gowns, etc. (really liturgical), but here is an amusing one. When Sancho Panza returns from El Toboso whither his master had sent him on a mission to the lady Dulcinea, Don Quixote, on seeing him, cried:—"What cheer, friend Sancho? Am I to mark this day with a white stone or with a black?"

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vincla purpurae et decem tibicinibus tollit etiam luctum." Wordsworth's text is: "extenuato igitur sumtu tribis riciniis (relictis) et uno claro (clavo) purpurae et decem tibicinibus tollit etiam lamentationem."

[6] In some provinces of Russia the coffin is sometimes wound with red threads, sometimes a red woolen thread is laid across the body. See *Archiv f. Religionsw.*, XV, p. 313–318, Rudolf Pagenstecher, "Rache puppen aus Mexico und Verwandtes," one of the dolls is also wrapped with red thread. "In this case needles and thorns are not enough to bind the rival. The figures are wound with threads to render any defence on the part of the bewitched impossible. (Refers to Von Duhn and Janiewitsch with the suggestion that in order to make the dead harmless the coffin is wrapped with threads and only as a final allusion a red thread is laid across the corpse.)

[7] See Jervons, T. B., "An Introduction to the History of Religion," London, 1896, p. 67.

[8] For other explanations of red see Professor R. Harris, "The Red Robes of the Dioscuri" in *The Contemporary Review,* No. 557, May, 1912, pp. 657–668.

"Your worship," answered Sancho, "had better mark it with red earth, as they do the college lists, to be more plainly seen by those who look."

Watts in his translation has a note: "Those who had won the degree of doctor at the Spanish universities were signalized by a mark in red chalk placed against their names."

When I was in Salamanca, in 1910, I saw the walls of the university buildings and even of the churches covered with the names in red paint of those who, with much tribulation, had won their degrees.

Now, what is the connection of all this with the expression "painting the town red"? Are we dealing with a case of survival or of atavism? A few years ago the students of Harvard defeated the Princeton baseball team. In the celebration which followed the town of Cambridge was painted vividly red and the statue of John Harvard, in the College Yard, was decorated as brightly as the Capitoline Jove. Strange to say not a member of the faculty seemed to realize what an interesting case of survival had occurred. Quite unanimously faculty and students rose in righteous indignation and cast out those whom they regarded as offenders. One of the exiles applied for admission to Cornell, and fortunately for him I happened at the time to be the dean of the Faculty of Arts and Sciences as well as one of the founders of the American Folk-Lore Society. It is needless to say that I welcomed, in my latter capacity, one who had been engaged in so interesting a proceeding, while in my capacity as dean I felt it was perfectly safe to admit him to Cornell, especially as at that time we had no statue of Ezra Cornell to decorate after our athletic victories.

APPENDIX A

I can not refrain from citing here an example of this custom which has been embedded in a work of modern literature. I allude to Schiller's "Nadowessische Totenklage" (1797), the source of which is very interesting. Jonathan Carver, born in 1732 at Stillwater, Connecticut, undertook extensive journeys through the western part of North America in the years 1766, 1767 and 1768. The first edition of his account of these travels was published at London in 1778, and a German translation: *Reisen durch die innern Gegenden von Nord-Amerika in den Jahren 1766, 1767 und 1768, mit einer Landkarte. Aus dem Englischen. Hamburg,* 1780, 8vo. pp. xxiv, 456, fell into the hands of the great poet.

Carver, in his Chap. xv, relates how the Naudowessies (Sioux), a tribe of Indians living west of the Mississippi, treat their dead. He says (London, 1778, pp. 399, seq.):

> After the breath is departed, the body is dressed in the same attire it usually wore whilst living, his face is painted, and he is seated in an erect posture on a mat or skin placed in the middle of the hut with his weapons by his side. His relations being seated round, each harangues in turn the deceased; and if he has been a great warrior recounts his heroic actions nearly to the following purport, which in the Indian language is extremely poetical and pleasing:

"You still sit among us, brother, your person retains its usual resemblance and continues similar to ours, without any visible deficiency, except that it has lost the power of action. But whither is that breath flown, which a few hours ago sent up smoke to the Great Spirit? Why are those lips silent, that lately delivered to us expressing and pleasing language? Why are those feet motionless, that a short time ago were fleeter than the deer on younder mountains? Why useless hang those arms, that could climb the tallest tree or draw the toughest bow? Alas! every part of that frame which we lately beheld with admiration and wonder, is now become inanimate as it was three hundred winters ago. We will not, however, bemoan thee as if thou wast for ever lost to us, or that thy name would be buried in oblivion; thy soul still lives in the great Country of Spirits, with those of thy nation that are gone before thee; and though we are left behind to perpetuate thy fame, we shall one day join thee. Actuated by the respect we bore thee whilst living, we now come to tender to thee the last act of kindness it is in our power to bestow: that thy body might not lie neglected on the plain, and become a prey to the beasts of the field, or the fowls of the air. We will take care to lay it with those of thy predecessors who are gone before thee; hoping at the same time, that thy spirit will feed with their spirits, and be ready to receive ours, when we also shall arrive at the Great Country of Souls."

Note on p. 403, Carver says:

One formality in mourning for the dead among the Naudowessies is very different from any mode I observed in the other nations through which I passed. The men, to show how great their sorrow is, pierce the flesh of their arms, above the elbow, with arrows, the scars of which I could perceive on those of every rank, in a greater or less degree; and the women cut and gash their legs with sharp broken flints, till the blood flows very plentifully.

Schiller's poem has been translated by Bulwer and Sir John Herschel. Here is the last stanza in the two versions:

The paints that deck the dead bestow—
Yes, place them in his hand—
That red the kingly shade may glow
Amid the spirit-land.

The scalping-knife beside him lay,
With paints of gorgeous dye,
That in the land of souls his form
May shine triumphantly.

The German is:

Farben auch, den Leib zu malen,
Steckt ihm in die Hand,
Dass er röthlich möge strahlen
In der Seelen Land.

APPENDIX B

Résumé of Hans Berkusky's article: "Zur Symbolik der Farben" in *Zeitschrift des Vereins für Volkskunde,* xxiii (1913), pp. 250–262.

If white is the color of death, so red, the brightest of all colors, is a symbol of life, for red is the blood, and blood and vigor are for primitive

man almost identical ideas. The custom of drinking the blood of slain enemies or of sacrificed animals or men to strengthen one's own energy is widespread to-day among numerous savage tribes; a wounded Somali (Ph. Paulitschke, *Ethnographie Nordostafrikas*, Berlin, 1893, p. 186) drinks his own blood with the notion that he can thus take again within himself the strength that is escaping with his blood.

Among the various means by which primitive man seeks to increase his vital energy, the drinking of blood is in all probability the earliest. The changes and development which this earliest form has undergone in the course of time may perhaps be distinguished as follows: the drinking of blood—the painting, anointing or sprinkling with blood or wrapping the sick in the bloody skin of a newly slaughtered animal—the painting of the body red or the tatooing of red figures, to which magic power is ascribed—and finally the wearing of red garments or red amulets.

That the red color, with which numerous primitive peoples paint their bodies, originally at least is to be regarded as a substitute for blood, follows from the fact that until the very present time by the side of the painting of the body with red color, perhaps the earlier form, the smearing of the body with blood has been preserved (Samter, *Geburt, Hochzeit und Tod*, p. 187, *Familienfeste*, p. 53).

Berkusky then takes up each of these topics and gives numerous references under each. I must omit until p. 253.

If primitive peoples paint their bodies red on festal occasions it probably arises from the fact that such festivals make an unusual demand upon their strength. . . . The original significance of this custom—to strengthen the vital energy, in many cases no longer clearly appears. The red color of the body is finally only a festal ornament, and because the primitive man is inclined to make the most of his outward appearance, he paints his body red.

The Dead (p. 254). The living are painted red, the dead should not be deprived of the ornament he has had when alive. In many cases, however, the red color is not an ornament but a substitute for the blood of animals slaughtered in honor of the dead. . . . The dead must strain all his energies to escape the numerous dangers, which threaten him on his journey to the other world, the dead are therefore painted red in order that they may overcome victoriously all calamities and trials.

Then follow references to painting parts of the body red, pp. 254, 255. As the bones of the dead, so other objects endowed with magic powers are painted red: statue of Jupiter, stones, idols, etc.

While (p. 256) the almost naked man applied the red color directly to his skin, in the course of time as the need of more clothing was felt, this custom was replaced by wearing red clothing and red amulets. These increased, it was supposed, the vigor of the body and its resistance to harmful influences of all kinds.

Sympathetic remedies, p. 257; amulets against the Evil Eye, etc., p. 258; Red in marriage customs, pp. 259–260; Red a lucky color, p. 260; Red animals in sacrifice, p. 261.

Finally, the custom is referred to of wrapping the dead in red garments or burying them in red coffins. This is done partly for the same reason as painting the dead red, and partly also to keep the dead in his grave; as red is a preventive against evil spirits so the dead will be hindered by the red color from leaving his grave and disturbing the living. (Berkusky gives many references to this custom in various lands).

A considerable number of references may be found in Henry Fairfield Osborn's "The Men of the Old Stone Age." New York, C. Scribner's Sons, 1916, pp. 290, 304, 305, 337, 379, 380, 476–79. See W. K. Morehead, "The Red Paint People of Maine," *American Anthropologist*, N. S. vol. xv, pp. 33–47, and Holmes (W. H.) Anniversary Volume, Washington, 1916.

APPENDIX C

Since writing the above paper a new explanation of the ceremonial use of red has been given by Rendel Harris in his *Boanerges*, Cambridge University, University Press, 1913, as well as in some previous essays, notably "The Red Robes of the Dioscuri" in the *Contemporary Review*, May, 1912. Mr. Harris sees in the red color the representation of lightning and says, op. cit. p. 31, "It has not, however, been as commonly recognized that the reason why the robes are red lies in the fact that the Twins are personifications of the lightning being either Sons of Zeus or Sons of Thunder, or Children of the Sky, or whatever other title may express their superhuman affinities.

Suppose then we start from the statement that red is the proper color for the lightning, and illustrate that statement by reference:

1. To the color ascribed to the Thunder-Bird, who is the zoomorphic representative of thunder and lightning.

2. To the color ascribed to the anthropomorphic representation of the deity who controls the thunder.

3. To the color worn by the priests and human representatives of the aforesaid deity.

If all these developments of the idea of thunder and lightning tell the same story of color, we shall have little doubt as to the meaning of that color when it appears in the raiment of the Heavenly Twins.

Earlier in p. 3, Harris says: We shall see by-and-by, when we examine into the cult of the Heavenly Twins more closely, that in almost every case in which the Twins are represented, in art, in worship, by an attached priesthood, or by appropriate sacrifices, one color dominates the representations, the red color of the lightning.

P. 41. "But it is not only Thor that makes the connection between the earlier zoomorphs of the thunder and the red color of the thunder. Jupiter Capitolinus himself was formerly a red-painted image; so that there could be no mistake in saying that he was, par excellence, the Thunder. He was fulminate, as far as color could make him, and strangely like the Northern Thor." . . . It has been pointed out, for example, that, in the old times, a successful Roman general, to whom a triumph was granted, was considered as an actual impersonation of Jupiter, and to fulfil that dramatic action he was painted red (Pliny, Nat. Hist. xxxiii, 36).

See p. 91 for absurd explanations of the barber's pole.[9]

See pp. 396, 397, for red color of "bull-roarer," etc.

[9] "But the explanation of the pole by blood and bandages has an unnatural look about it. Perhaps if we examine more closely into the history of surgery we may see the matter more clearly. Who are the patron saints of surgery? The answer of the mediaeval world will be at once, Cosmas and Damian, the saints who healed without taking fee, the Christian heirs of Aesculapius and of the Heavenly Twins. The barber's pole is, then, the sign of Cosmas and Damian: but Cosmas and Damian are the Heavenly Twins: then the red and white stripes are the sign of the Sons of Thunder. The induction is too rapid to be altogether satisfactory."

THE ORIGIN, NATURE AND INFLUENCE OF RELATIVITY[1]

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IV. The Experimental Tests of Relativity

It would be impossible to limit speculation about physical laws by the demand that a theory must apply in all respects. The vortex theory of the atom has always been considered to be of great interest, although never applied successfully. A theory of major importance will have many applications, of course, and may suggest the way to new discoveries. Thus the Newtonian formulation of gravitational law led to the discovery of the planet Neptune through the observed irregularities in the motion of Uranus.

The theories of relativity are unquestionably of very high speculative interest. The extent to which they will be found in harmony with nature is not yet fully disclosed. If a just estimate of them is desired, it is necessary to adopt the spirit of impartial inquiry in dealing with the relevant experimental facts. In this critical spirit it may be asked whether or not there is some common ground which furnishes a satisfactory basis for consideration of the questions at issue. It has been pointed out previously that there is an extensive basis of this kind.

In the first place, it is agreed that the measurement of time by more or less arbitrary means is possible so that events can be classified by means of their time of happening, while the events happening at a particular time can be spatially classified in various ways, this last classification requiring three space measurements. An event, such as the collision of two atoms, is the elemental physical reality specified by these four measurements, and the totality of events constitutes the substratum of the physical universe now called space-time.

Furthermore, it is granted that material objects can be identified, and followed in time. Any such object occupies a definite part of space at any time. It is assumed that there is the possibility of continuing this process of identification of objects down to the point particle.

Solids, liquids and gases may be subdivided. However, chemists, in their consideration of the various kinds of matter, have been led to the conclusion that they were made up of indivisible atoms of a definite type for each chemical element. This conception has proved of great simplifying power. More recent advances make it plain

[1] Lowell lectures.

that electricity also is atomic. Magnetism is held to be merely electricity in circulatory motion. These elementary units of matter and electricity have spatial extension. Besides these, there is only space-time free from matter and electricity.

Let us turn now to the consideration of nearly empty space-time and review the generally accepted facts briefly. For the moment let us adopt the notion that a clock is available at each particle to measure the lapse of time there, and that light disturbances can be observed which originate at other similar particles. If it is assumed that such a space-time is alike in all its parts, it follows conclusively that with any such particle may be correlated an optical system of space and time, with reference to which all other particles will travel at a constant velocity in a straight line, while light travels with one and the same velocity under all circumstances.[2] The conviction that space-time, remote from material bodies, is homogeneous and of one nature throughout, has the same reasonableness as the conviction that all parts of a plane are alike. The experimental method of spatio-temporal measurement employed may be based upon a process of light signaling between three particles relatively at rest, and the use of a clock at one of them. The space obtained by such methods will be Euclidean.

Here is a considerable basis of facts about which there is no dispute.

In the spaces and times attached to small particles in empty space-time, there may happen to exist a unique one of simplest type from a physical point of view. This will be the space and time of a set of particles "at rest." It will then be legitimate to call such a space and time *absolute*, and so we arrive at classical physics. The only alternative is that all the spaces and times are on exactly one and the same physical footing. This hypothesis yields the special theory of relativity. Which of these alternatives really holds?

The understanding of the situation turns upon the highly difficult and interesting concept of the clock. The ordinary pendulum clock itself does not conform to what is meant; such a pendulum clock and the earth together more nearly constitute a clock in the technical sense. This particular type of gravitational clock would have to be of small dimensions for purposes of exact temporal measurement in nearly empty space-time. A pocket watch would be more nearly a clock of the desired type. Even for this elastic clock, uniform conditions of operation would be essential. There would be required constant pressure and temperature, and freedom from gravitational, electric, magnetic or rotational stress. A body like

[2] This is true because the light-second is defined as the unit of distance.

the earth in rotation furnishes a type of rotational clock. In fact, as soon as phenomena are regarded from the proper point of view, it appears that more or less exact clocks are omnipresent in nature.

Now the statement that the universe of events is four-dimensional has no real meaning unless it is possible to identify events of a specific type T exactly. It has been assumed that particles are identifiable. The events at a particle are evidently arranged in a time order. Now if two events A and B of the particular type T happen at a particle, an interval between the two events is set off. An indefinite recurrence of such events measures the time order at this particle, and similarly at other particles, and thus the comparison of time intervals elapsing at different particles becomes possible. In other words, such a sequence as A, B functions as a clock of type T. Thus it seems clear that the mere possibility of spatio-temporal measurement involves something of the notion of the clock at any particle.

However, in both the old and new theories, the physical reality of the local interval of time is conceded. Hence it is clear there must exist appropriate ideal types of local clocks with which this quantity can be measured. Of course the ideal clocks used must run at the same time when together, and even when relatively at rest. There will then be physical significance in the relations between the spaces and times of various particles.

If two such clocks are separated and later brought into coincidence, it does not follow that the same length of time has necessarily elapsed on both clocks. To assume the contrary is to require the existence of absolute time.

When there is more than one kind of clock, as M and N, so that if a clock M has the same rate as N at one particle, it need not have when brought again into coincidence with N at some other particle in relative motion with respect to the first, then a difficulty arises as to whether M or N is the selected ideal type of clock. Thus, a vibrating sodium atom may be called a clock M; an oscillating spring may be taken as a clock N. If the interrelations of the various spaces and times are to have genuine physical significance, it is impossible to evade the demand that these and other kinds of clocks shall keep the same time at every particle, *unless one selects arbitrarily a particular kind of clock as ideal.*

If there is a unique physical reality, corresponding to our naïve feeling of duration at any particle in empty space, it is reasonable to suppose that all clocks will measure that duration. Nevertheless, the classical physics of Newton and Faraday has more than one type of clock. Thus an oscillating spring yields an elastic clock in the

meaning of our definition. Likewise, a pair of mirrors mounted at the ends of a rod, between which light is flashing back and forth, forms a 'light clock.' Either of these possesses the fundamental properties required. Now will these two clocks keep the same time? The answer is in the negative, since, according to the formulation of the laws of motion, only the elastic clock will measure *real* intervals of time, while the light clock will go more slowly with respect to the elastic clock, the larger its absolute velocity. But why should either be preferred? It is difficult to find any genuine reason for the choice made.

It will be seen from this very simple example that the behavior of these two types of clocks would enable us to single out the absolute space of Newton and Faraday; it will be that space in which the light clock at rest runs most rapidly relatively to the elastic clock at rest. The corresponding time measurement can then be called absolute time. An absolute system of reference is determined.

This is not accidental. When relativity does not exist, all particles in empty space are not on a physical parity. The distinction between them will affect the types of clocks in various ways, and thus their relative rates at different particles.

The test of relativity is thus seen to be that small local clocks of any type will run at the same rate whenever and wherever brought together at a particle in empty space, provided that their rates have once been synchronized by proper choice of a unit of time, say the second.

The test of the alternative possibility of absolute time and space is that at least two kinds of clocks can be found in nature.

These will be related to one another as the elastic and light clock cited above are in the space-time of Newton and Faraday.

With the phrasing of the distinction in such simple terms, the immediate consideration of the facts is in order.

Here a remark must be interpolated in fairness to the classical theory. The possibility of accepting it lies in the fact that bodies found in nature have a small *absolute* velocity, *i.e.*, that the space attached to the sun or any star is very nearly the absolute space. If this were not the case, the fact would be revealed in various ways, for example, by the asymmetric behavior of the spectra of the stars. Now when absolute velocities are small, it is not difficult to prove that relativity of motion will be simulated to a considerable extent. Witness the aberration of light and the Doppler effect, as explained on the old basis. These turn out to depend, as far as the principal effect to be observed is concerned, on the relative velocities only.

Hence, when we are dealing with bodies moving at low relative velocities, it is necessary to achieve a high order of accuracy in any

crucial experiment. Since the ratio of stellar velocities to the velocity of light is of the order of one to one thousand, the method will have to possess an accuracy of one part in one million. There are not many experiments in which such a degree of accuracy can be obtained, but they are of great interest.

The equations of Maxwell have always been accepted as applicable to electromagnetic waves in empty space-time, where the space and time are obtained by ordinary means of measurement. The velocity of these waves can be determined theoretically and experimentally; it is independent of the frequency of the exciting electric oscillator, and is the same as the velocity of light. This last fact, and the very great parallelism between the optical and electrical behavior of the elements, extending to the equality of corresponding optical and electrical constants, indicate that the light wave is merely an electromagnetic wave of very high frequency. There must then be something in the characteristic atomic units from which these light waves are derived which is of the nature of an oscillator or atomic clock.

The wave character of light is conclusively demonstrated by the phenomenon of interference, according to which two beams of light of the same frequency may interfere to yield darkness. By this means the most exact measurements of length can be made.

In the celebrated Michelson-Morley experiment of 1887, a beam of light was divided, sent along two bars and then brought back to interference. If there had been any variation in the relative rate of the atomic clock from which the beam of the light came, and the light clock formed by the beam and the bars, with the varying velocity of the earth, there would have resulted a slight shift of the interference bands. One hundredth of the shift expected under the classical theory would have been within the reach of observation, but none was found.

The meaning of the experiment is that the light clock and the atomic clock run at the same rate. Another way of stating the meaning of the experiment is to say that the shape of any undisturbed body will always be the same in the reference space and time which belongs to it, as measured by light signaling and the atomic clock, or by the measuring stick. From a logical point of view the experiment is corroborative but not crucial.

Another kind of clock can be defined as follows: Consider a tube filled with water and not rotating, and a beam of light which traverses the tube. It will take a certain interval of time for the beam to traverse the tube of water, as measured in the attached space and time. This will then yield a new kind of clock.

The situation may be looked at as follows: If there is an absolute space, and the tube is not at rest in it, then in the space attached

to the tube, the absolute space or ether will appear to be moving through the tube in some particular direction. A beam of light which travels in the same general direction as the ether would seem likely to have a different velocity than when sent out in the opposite direction, and this difference in velocity ought to be measurable, provided that the ether is in any sense a medium as the water is. In other words, the new kind of clock would be expected to yield a measure of time, differing according to the absolute velocity of the water.

Here again no effect of the anticipated kind revealed itself under most careful duplication of the Fizeau experiment.

It is generally held that the Michelson-Morley experiment takes a central position in the experimental testing of relativity. Hence, it is of importance to see how it has been interpreted by those who hold to the old theory of space and time. The hypothesis of ether drift has been advanced as an explanation, according to which the earth carries the ether in its vicinity along with it. Since the original experiments were carried out in a building, such a drift was felt to be especially likely to cause the negative result.

The logical difficulties involved in the concept of ether drift can not be too strongly emphasized. On any previous theory the ether was a particular absolute space singled out by its property that light traveled in it with the same velocity in all directions. There was now tacitly assumed to be some further underlying reference frame—the true space—with no definite physical properties.

Nevertheless, it was of great interest to repeat the experiment, preferably upon a high mountain, as D. C. Miller did at Mount Wilson in 1921. His measurements indicated a shift in the bands of about one fifth that required by the classical theory. A second effect, not expected on any theory, was also found. After elimination of direct disturbances from ordinary heating and magnetic action, these two effects remained. However, the error due to radiant heat requires further investigation and seems likely to explain the two indicated small shifts observed.

Some physicists and astronomers, in opposing the new theories, are willing to accept the Lorentz contraction hypothesis in the interpretation of the same experiment. This is particularly difficult to understand because Lorentz accepts the theory of relativity as the proper expression of his own hypothesis. The reason for the essential equivalence was presented earlier.

The fact is that Einstein has provided the reasonable way out of a dilemma in which physics was placed by various experiments like those referred to above. Without the readjustment of the

concepts of space and time, to the exceedingly slight extent contemplated in the special theory, theoretical physics would be in a difficult position to-day.

The electromagnetic equations of Maxwell have a complete relativistic form to begin with, while the equations of classical mechanics can be modified slightly to correspond. The behavior of an electrified particle at velocities comparable to that of light under electromagnetic forces is found experimentally to follow the law thus obtained. It can be said that the known facts of mechanics and electromagnetism are then adequately accounted for. When this is not done, the attempt to explain the facts seems to lead step by step to complete relativistic form. The obvious inference is that the easiest manner in which to grasp the physical situation is to assume the principle of relativity at the outset. If we refuse to do so, the difficulties seem endless. The immense usefulness of this spatio-temporal principle of relativity has been pointed out previously.

The argument of convenience thus becomes paramount. It is the same consideration as that which established the Copernican theory as against the Ptolemaic.

Moreover, no mean philosophical importance attaches to the fact that, if absolute space and time exist, then the interval of local time is devoid of a unique physical meaning. The theory of relativity has the unquestionable superiority that for it local time has physical reality.

The notion that the interval of local time is a basic reality may be looked upon as the guiding principle of the general theory of relativity to whose experimental verification we turn next. Its successes afford substantiation of an important kind for the special theory.

The interval of local time between events at a particle suggests the distance between points of a line to the mathematical mind. Minkowski pointed out that the space-time of the special theory was analogous to a flat surface. According to the general theory of relativity, when matter is present in large quantities the space-time is analogous to a curved surface. It is such a curvature which is held to account for gravitation. On the basis of the hypotheses that the well-known purely mathematical measure of curvature indicated the density of matter and energy, and that empty space-time was as flat as possible, Einstein obtained a definite theory which explained the observed laws of gravitation. The new gravitational law was as uniquely determined as that of Newton. Consequently, the tests of the theory by means of the slight predicted differences may be regarded as especially conclusive.

The variations from the older theory were declared by him to be within the reach of observation in three cases, all of them depending upon the large mass of the sun as their cause.

Firstly, there must be a rotation of the line of symmetry of the orbits of the planets in their revolution around the sun, by an amount in excess of that demanded by the Newtonian theory. This additional effect is largest in the case of the planet Mercury. Fortunately, the angular advance of the perihelion of Mercury had been measured with accuracy. Before the theory of relativity was thought of, there had been found an advance, beyond that expected on the Newtonian basis, of about forty seconds a century. This unexplained fact had been held to be the one real difficulty in the way of a complete success of the Newtonian theory as applied to the planets.

The Einstein theory indicated an advance of the right amount for the perihelion of Mercury, and advances of the right order of magnitude for the other planets. These are of minor importance compared to that of Mercury in the opinion of astronomers generally. When it is borne in mind that, if the advance had been of any other amount, it would not have been possible to readjust the Einstein theory to suit it, the importance of this verification is obvious.

It is possible to account for the same advance by properly distributing fine particles of matter about the sun. The most competent opinion is that there is no evidence for such matter in the amount required.

The second effect to which the theory led had to do with a hitherto unobserved phenomenon, namely the apparent bending of star light near the sun. The abandoned corpuscular theory of light of Newton led to the idea that bending might occur, due to the gravitational attraction of the corpuscles by the sun. The amount to be expected on the Newtonian basis is eighty-seven seconds. Einstein arrived at the same quantitative result by a different method in 1911. The paper of 1911 was interesting, as the forerunner of the paper on general relativity of 1915. According to the general theory, the amount of deflection to be expected is nearly double that predicted on the Newtonian basis.

In order to test the prediction, English astronomers made special expeditions to observe the total solar eclipse of May 29, 1919, and found evidence of a bending of light of about the amount indicated. The measurements require the utmost skill. The observations agreed with the Einstein theory within the limits of error (about 20 per cent.), and were held to constitute another definite confirmation of the theory. Nevertheless, it was extremely desirable that further observations should be made in order that the results be definitively established.

The first occasion for so doing was furnished by the solar eclipse of September 21, 1922. An American expedition under the direction of W. W. Campbell was successful in obtaining an excellent set of photographic plates. The plates showed a radial displacement of the star images of the magnitude demanded by the Einstein theory. The mean value from four plates gave 1.72″ as against Einstein's predicted value of 1.74″. The probable error of the plates was only .11″. This initial result was in extraordinary agreement with the theory.

The notion has been advanced that the gaseous matter which exists in the neighborhood of the sun may have caused refraction of the star light. However, our knowledge of the sun's outer neighborhood is sufficient to indicate that this is an insufficient explanation.

The third effect to be expected according to Einstein was a shift of the solar spectral lines of any element toward the red end of the spectrum, as compared with a terrestrial spectrum. This is exceedingly difficult to detect, although the general consensus of opinion among those who have investigated it, has been that the shift toward the red does exist. The latest announcement by St. John, made on the basis of new knowledge concerning the solar envelope, is favorable to the theory. It is "that three major causes are at work in producing the regular differences between solar and terrestrial wave lengths and that it is possible to disentangle their effects; namely, the slowing of the atomic clock in the sun to the amount predicted by the general theory of relativity, radial velocities of moderate cosmic magnitudes and of probable directions, and differential scattering in the longer paths traversed by the light coming from the edge of the sun."

All things considered, the experimental facts bear out the new theories. The results point toward the physical uniqueness and reality of the local interval of time but not of absolute time, the relativity of physical law to any undisturbed particle in empty space, and gravitational law as merely the cosmic result of the direct conditioning of space-time by the presence of matter. These conclusions are of major importance for physics.

THE EARLY HISTORY OF TERRESTRIAL MAGNETISM IN THE UNITED STATES WITH SPECIAL REFERENCE TO THE WORK OF DR. JOHN LOCKE OF CINCINNATI[1]

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THE period centering about 1840 was remarkable in our country for the number of able and zealous investigators whose devoted labors enriched science in various fields—notably in astronomy and the earth's physics. And the city of Cincinnati has the honor of having numbered among its citizens two of the most distinguished men of science of that period—Ormsby M. Mitchell, the founder of the Cincinnati Observatory, and John Locke, one of the foremost pioneers in terrestrial magnetism, whose studies in that and related subjects won him distinction both at home and abroad.

Dr. Rufus has told us of the leading part taken by Cincinnati and Mitchell in the inauguration of astronomical work in this country. Dr. John Locke, of whom it is my privilege to speak especially, likewise contributed notably to the advancement of American astronomical science by his invention in 1848 of what he first called the "Automatic Clock Register," but later the "Chronograph," the term now generally in use. Thanks to the interest shown in this invention by Lieutenant Maury, the United States Congress was induced to contribute $10,000 for the perfection and construction of a chronograph for the National, now known as the Naval Observatory.

Through the kindness of one of Dr. John Locke's sons, the late Colonel Joseph Morris Locke, whose acquaintance I had the privilege of making when I was a resident of Cincinnati, I was enabled to see many of the scientific instruments and books used by his father, and to look over his note-books and papers. I might mention in this connection that Colonel Locke was the inventor of the Locke level, well known to engineers. He died in Washington in 1917.

Professor John Locke, M.D., was born in Lempster, New Hamp-

[1] Presented before the History of Science Section of the American Association for the Advancement of Science, Cincinnati, December 29, 1923.

shire, February 19, 1792. He was a descendant of William Locke, who sailed from London, England, in the ship *Planter*, April, 1635, for the Massachusetts Colony, and in line of descent from whom was Samuel B. Locke, president of Harvard University. Collateral branches furnished professors to Dartmouth College and other schools of learning.

His grandfather, father and brother had a fine reputation in New England as expert engineers and millwrights, or hydraulic engineers, as they would now be called. The family had for a time no settled home, but moved about from place to place wherever the father's business called him. They finally settled at Bethel, on the Androscoggin River, in Maine.

His father had a very good private library for those days, which was a great help and incentive to his son. When the youth had exhausted all local means of obtaining an education, he desired to carry on his studies elsewhere. This desire his father opposed, as he wished him to take up his own profession of millwright. Locke was thus obliged to continue unaided his efforts to obtain an education. For a while he was an assistant in Professor Silliman's laboratory at Yale. Later, he was curator of botany in Harvard. In 1818 he was appointed assistant surgeon in the United States navy. In 1819 he graduated in medicine at Yale College.

In 1821 he went to Kentucky and organized an "academy for females" at Lexington. The following year he removed to Cincinnati where he established the "Cincinnati Female Academy." In 1825 he married a favorite niece of the late Nicholas Longworth of Cincinnati. Ten children were born to them, only one of whom is still living—a daughter. In 1835 he was appointed professor of chemistry and pharmacy in the Medical College of Ohio, which chair he occupied with signal success for eighteen years.

In 1837 Dr. Locke visited Europe, where he was cordially received by scientific men. On his return to this country, he was connected for a time with the first geological survey of Ohio. In 1839 he was appointed to take part in the United States geological exploration of the mineral lands of Iowa, Wisconsin and Illinois. At Philadelphia, April, 1840, in connection with others, he organized the American Association of Geologists and Naturalists, and presided at many of its meetings. This association, by gradually incorporating other branches of science, developed into the present American Association for the Advancement of Science.

From 1838 to 1848 Dr. Locke devoted a great deal of labor to perfecting a connected survey of the magnetic dip and intensity of the northern portion of this country. In recognition of his labors in this connection, the British government, at the suggestion of the most distinguished British magnetician of that time, Sabine, pre-

sented him with a magnetometer and theodolite by Meyerstein of Göttingen. (It is believed that these instruments are among those presented by Lieutenant-Colonel Morris E. Locke to the Virginia Military Institute, of which he is a graduate.)

Dr. Locke resigned his position in the Ohio Medical College in 1853. The following year he moved to Lebanon, Ohio, but returned to Cincinnati in 1855, much broken in health. He died on July 10, 1856, at the age of sixty-four years. The scientific instruments used by Dr. Locke in his teaching and investigational work have been dispersed among the following possessors: Mr. F. G. Hunt, a former Cincinnatian, now of Washington, and a friend of the late Colonel Joseph M. Locke; Lieutenant-Colonel Morris E. Locke, a grandson of Dr. John Locke; the Ohio Mechanics Institute; and the Virginia Military Institute.

Dr. Locke made notable additions to our knowledge in various sciences. His unselfish devotion and many valuable contributions to the science of terrestrial magnetism certainly deserves more than the passing notice we can here give them. His investigations and magnetic surveys from 1838 to 1848 extended from the southern part of Kentucky to the northern side of Lake Superior, and from the state of Maine to some distance beyond the Mississippi. They were conducted almost entirely at private expense and with an enthusiasm and zeal worthy of the cause. His observations were the first to give indication of the situation of the American focus of greatest magnetic intensity, his results being verified by the later investigations of Lefroy. His excellent investigation of local deflections of the magnetic force, as exhibited notably at the Palisades of the Hudson, constitute a valuable contribution to our knowledge of the subject. It is possible that he may have the honor of having made the first absolute (or even differential) determination of the magnetic intensity.

He proposed to make Cincinnati the base of reference of a magnetic survey of the United States, and calling the value of the earth's horizontal intensity at Cincinnati unity, he determined the horizontal intensity in terms of this unit at stations in the United States, Canada and Europe.

All honor to the British government and Colonel Sabine that, when Dr. Locke's appeal for aid from American societies then in existence could not be responded to, they saw their way clear towards supplying him with the desired instruments, and thus, by their recognition of the value of his labors, gave him the stimulus and encouragement so desirable to every true investigator of nature's secrets!

SCIENCE TEACHING IN SOME EUROPEAN SCHOOLS

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IT was the good fortune of the writer to spend seven months in Europe in 1922 and 1923 during which time many schools were visited in order primarily to study the teaching of science. Most of the time was spent in France, for it seemed best to settle down and live among the schools of one country to understand them reasonably well, then to visit those of other countries for comparison, rather than take a hasty and necessarily superficial survey of the schools of many lands. This policy was early justified, for it was found necessary to discard most of the information gathered during the first month because the terms used in conversations with schoolmen carried such different meanings to them and to myself. Thus, "science" there includes mathematics. Inquiry was made concerning "courses of study," but when such were obtained they proved to be syllabi of particular subjects. The terms "elementary school" and "primary school," used interchangeably in this country, signify quite unlike things over there. The French schoolman uses the term "lecture" but means thereby a reading, while he uses the term "conference" with the significance of our word lecture. You do not visit a class; you assist at a class. So it was necessary, in all inquiries and discussions, to make sure that each understood the other's educational terminology. One might gather much misinformation by a hasty survey of European schools.

France is divided into fifteen districts for the administration of its academic school system. The administrative officer of each district is the rector (we should say president) of a national university; one such university is located in each district. The minister of public instruction is the director of the whole system. These districts are not coincident with the present political divisions, which are the eighty-nine departments, nor do they coincide with the old provinces that still hold over locally as designations of portions of the country. There are then fifteen national universities. Beginning with the University of Montpellier on the Mediterranean coast and swinging about Paris as a center in a clock-wise direction there are, in addition to these two, universities at Toulouse, Bordeaux, Poitiers, Rennes, Caen, Lille, Nancy, Dijon, Besancon Cleremont, Lyons, Grenoble, Marseilles.

It is evident that the rector of a university can not, in addition to university administration, be familiar with the details of a national school system or even with those of one district. So the real administrators of the normal, secondary and elementary school systems are secretaries to the several rectors, and these secretaries are chosen for their knowledge of the affairs of such schools.

While the academic school system is administered as a unit that does not mean that the whole French school system is so administered. Quite the contrary is true. Commercial schools are under the direction of the minister of commerce, agricultural schools are administered by the minister of agriculture, schools of diplomacy by the minister of foreign affairs, technical schools by the minister of labor, etc.

The French academic system now in vogue consists of free elementary schools, pay lycées and colleges, normal schools and universities. The elementary school receives children as young as three years of age and gives them eight years of training, a possible three years of kindergarten, and five of elementary work which is normally completed at ten or eleven years of age. The elementary schools are practically all in towns and cities for there is no country population living on the farms. Our "little red schoolhouse" has no counterpart on the continent. The people, even the farmhands, live in villages on the great estates.

The lycées were originally founded and maintained by the cities. Then the smaller communities demanded schools of similar grade, and the state established and largely maintained the colleges in the smaller towns. Now this distinction in method of maintenance has largely disappeared. One still finds, however, that the secondary school of the city is usually a lycée, that of the smaller community a college. In both there is a seven-year course of study that leads to the bachelor's degree, which is achieved at the age of seventeen customarily.

As a matter of fact one finds the French lad of well-to-do parents going to the pay lycée or college from the very first, because something of a social stigma attaches to attendance at the elementary school where the children of the poor receive free instruction. The Frenchman of professional rank, or even the prosperous mechanic feels quite insulted if you ask him if his children attend the elementary school. So, very early in their history the lycées and colleges tacked on below their regular course an eight-year "primary" course, the counterpart of the "elementary school" course, except that pupils must pay tuition for it. The French boy usually, therefore, receives his B. A. from the same school which he entered as a kindergartner.

The schools for boys and girls are quite separate, though in a few communities it is customary to instruct them together in the kindergarten. In the smaller communities the boys' school and the girls' school may be under a common roof, but there is an unbroken wall of partition between them and the playgrounds are similarly separated. The teachers in the boys' schools are men. Since the war the girls' lycées and primary schools are taught quite commonly by women. The course of study in the girls' lycée is quite different from that of the boys' lycée and does not result in a bachelor's degree. If the girl desires to take such a degree in order to go on to the university, she must in addition to the regular course of the girls' school take several other subjects and prepare by tutoring for the final examinations that boys regularly take.

In the elementary and primary schools about one hour a week is, according to the program of studies, devoted to object lessons out of a total of twenty hours of instruction. The prescribed work is, for the first year, acquaintance with such simple things as direction, time, seasonal changes, the differences between minerals, animals and plants; for the second and third years the occupations and products that touch daily life, such as that of the miner and coal or iron, the vineyardist, grapes and wines. The fourth year is devoted to the common animals and plants of field, forest and garden that are of economic importance, and the fifth to the materials used in construction together with some elementary physical geography.

This material is presented in talks by the teacher or in a series of small books used as readers. Since it is in the course of study which is prescribed uniformly for all schools by the central authority, the science work is given, but as a rule it is perfunctory and formal. The children are supposed to get the necessary background of experience for themselves. There are of course occasional teachers who are sufficiently enthusiastic to bring nature materials into the school for actual study at first hand, or even to take pupils out of doors for such study outside of school hours, but they are the exceptions. Pretty much the same sort of work is prescribed in the French cantons of Switzerland, and the work is done in about the same way. In the English schools object lessons are not a specified part of the work of the corresponding grades, though they may be given. They are given when some school is sufficiently interested to put them into its course and get the approval of the authorities for such action, and in some schools nature work is given very well. There is an English Nature Study Society corresponding to our American Nature Study Society that undertakes to encourage such instruction in the schools and that in the interest of such work publishes the equivalent of our *Nature Study Review*.

On entering the lycée or college the French pupil must decide whether he will pursue the classical course or the scientific. At the beginning of the fifth year of the lycée these courses split again, the classical into the Latin-Greek and the Latin-Modern Language, the scientific into the Science-Latin or the Science-Modern Language. This subdivision is not maintained in the last or seventh year of the lycée, but the classical group of pupils is then known as the philosophical, the scientific as the mathematical group. The work in science may be described for the classical and scientific courses, for there is no variation in the subject-matter presented in the latter when it splits in the fifth and sixth years, and but slight differences between the Latin-Greek and the Latin-Modern Language courses.

Classical students have one hour per week in zoology through the school year, the first year of the lycée (corresponding in age of pupils to our sixth grade), one hour the second year in botany, one the third in geology, no science the fourth year, one hour of physics and chemistry combined and one of geology (reduced to twelve lectures for the Latin-Greek students) in the fifth year, one hour of physics the sixth year, two hours of natural science and three divided between physics and chemistry in the seventh year. In addition the Latin-Greek students have twelve lectures in hygiene in this year. This totals eleven year-hours of science out of a total of 172 year-hours of work in the seven years, or nearly 6.5 per cent. Even the classical students can not complete their lycée or college work without some considerable contact in primary and secondary school with the sciences.

Scientific students have two hours of zoology per week during the first year, two hours divided between botany and geology in the second year, two hours divided between physics and chemistry in the third year, one hour of zoology and two of physics and chemistry in the fourth year, five hours of physics and chemistry and one hour of geology in the fifth year, five hours of physics and chemistry in the sixth year, seven hours of physics and chemistry and two of natural science in the seventh year. This totals 29 hours out of a total of 178 year-hours of work or 16.3 per cent. Notice that of the 29 hours, the biological sciences are apportioned only four hours, while physics and chemistry have, between them, 21. Note also that aside from the fact that physics and chemistry run parallel, the science subjects as a rule come in successive years. If we should attempt to express the equivalent of the French science instruction in the lycées in terms of the American system for pupils of corresponding ages it would mean that pupils would receive in grades six to twelve inclusive a minimum of a year and a half of

science-instruction five times a week and a maximum of four years.

The science courses in French universities are so like corresponding courses in American universities that, barring the difference in language, one would hardly know whether he were in a French or American institution. There is this very marked difference, however, that the courses that may be offered are prescribed by the central authority, and the content of them is similarly determined in considerable detail. So that the courses offered in any subject in different universities are quite exactly replicas of one another. The same thing holds true for lycées and primary schools. The work in one city is like the corresponding work in every other. The text-books are identical, so that a pupil moving from one part of France to another fits into the system as well in his new locality as in his old home. The French university professor presents his subject-matter by lecture as a rule rather than by text-book assignment and recitation, and there is little or no opportunity for questions from students or for student discussion of the topic presented. The science laboratory work is quite informal, as it is in our own schools. The instructor moves from table to table to give help, to supervise the students' work and answer queries. The laboratories are as a rule plainly at times meagerly furnished but equipped adequately for work.

The lecture method of presentation maintains also in the lycées and even in the primary school to a large degree. The text-book is of secondary importance. It was a matter of pride among administrative officers in the school system, often expressed to me, that "our teachers know their subjects so they can present them effectively, they do not have to send the pupils to text-books to learn." While in each subject in the lycée there is an authorized text the pupil uses it merely to clarify points he may not have thoroughly understood from the teacher's presentation. And he is free to use any other or many other texts if he so wishes, so long as he acquires a mastery of the matter given in the lectures.

There is no provision for laboratory work in science in the lycées, except in those with a distinct prevocational trend. The science department in the lycée is supplied with good demonstration apparatus in physics and chemistry as a rule, and during or after the lecture the experimental work is well given by a demonstrator, an understudy of the professor. I was informed that pupils were free to repeat the experiments for themselves, but such work would have to go on at the general demonstration desk of the professor which is too small to make such experimentation possible to more than a small fraction of the class. The lecture demonstration is evidently the chief reliance of the science instructor in the lycées.

And in the sciences other than physics and chemistry the demonstration is often farcically insufficient or entirely wanting. I recall one lecture on the internal structure of the coelenterates at which the instructor passed a small whole sea anemone, preserved in a test tube, and a specimen of coral as the sole exhibits; that is quite typical.

In very many cases, judging from my own observations I should say in the majority of cases, the building used for school purposes in France, from universities down, are buildings designed for other uses and they do not fill educational needs. So that the science departments as well as others are inadequately and inconveniently housed. There are some very beautiful university, normal school, lycée and elementary school buildings constructed for these specific ends, but such schools are all too frequently housed in old palaces, convents or monasteries. Crude board benches and desks that have descended from a time when monks crucified the flesh by their use are still in common use. France has not been lavish in building or equipping schools. Some of the recently constructed Paris lycées by their elegance indicate a more liberal policy. The Swiss schools seem more adequately and more elegantly housed as a rule, as do the English. Oxford is the achievement of ideal scholastic beauty both in the charm of location and environment and in the impressive multiplicity, mass and grace of her buildings. Some of the great public schools are marvelously impressive. The standards in secondary and primary school buildings in the smaller cities are excellent in both Switzerland and England.

When a boy in a science class of the lycée is called upon to make a topical recitation on some phase of the subject that has been previously presented in the professor's lecture he responds as a rule in a very creditable manner. He steps to the blackboard, clearly and logically states the matter and reproduces rapidly and effectively the diagrams with which the topic was illustrated by the instructor. He displays a well-trained memory and usually ability to think clearly. The pupils, as I heard them recite in France, Switzerland and England, make better topical recitations than in corresponding American schools. They know the subject-matter, are remarkably apt in stating this knowledge, and do not limit themselves to monosyllabic replies to the teacher's questions. It seemed to me that the French lads have a genius for mathematics and physics, and that these of all the sciences are particularly well done.

One is impressed with the atmosphere of seriousness in the lycées as compared with that of our high schools. There is apparently less frivolity, more concentrated effort looking toward a mastery of the

subjects presented, less attention to outside matters, in a word, more of the atmosphere of a professional school than of a secondary school. This difference in attitude of mind of the French and American school boy of similar age is easily accounted for.

The object of the French schools is to eliminate the unfit, to pass on the fit as speedily as possible to their appropriate trade or professional schools. The boy gets out of the elementary or primary school into the lycée or college and out of it into the university only on passing notoriously rigid examinations. Sixty per cent. of the boys who come up for the final examinations of the lycées each year fail to pass. Some of them, of course, persist, "read" for another year or even for several years until they finally pass. But many are deterred by their failure from entering a professional career and go into a trade or into business. On the other hand, it is the purpose of our American school to give to each prospective citizen the best education of which he is capable. We encourage him to stay in school and get all he can, even if his ability is distinctly limited. The French lad seriously faces examinations that bar his way to the achievement of his dear ambitions. The American lad perfunctorily takes his examinations, knowing that he will probably pass and that if he does not it is not a serious matter; he can try some easier subject. The American pupil's examinations come subject by subject, the French lad's on his entire course.

The French lad in the lycée sees his professional education beginning immediately on the completion of his course. He begins his study of medicine or law at seventeen or eighteen normally, and if he is precocious two or three years earlier. For he does not have to attend the lycée a given number of years or take a specified number of courses. He has simply to pass the final examination to obtain his bachelor's degree. By extra tutoring a lad of parts can and often does begin the course in medicine or law at fourteen or fifteen. In this country, in our best professional schools we postpone the entrance by requiring a college course in addition to the high school course, making sixteen years of schooling prerequisite to the professional school in place of the French lad's twelve or ten. We hope thereby that the entrant will have time to mature sufficiently to profit by his professional training. The French seem to force that maturity by facing the boy early with his professional responsibilities.

Then the French lycée instructor has no hesitation in using corporal punishment to enforce discipline. The schools have a military atmosphere of sternness and rigor. The lazy lad knows that lessons must be learned or he may suffer a flogging. Furthermore, the lycées and colleges are all boarding schools. Pupils from the

small country towns come to the city schools and live at the school. Some of these pensionnaires may go home for week ends, but the majority are in the school constantly. Even the day pupils from the city in which the school is located come to the lycée to study and play under supervision of the teacher at seven in the morning and leave at six in the afternoon. A few will come only for the recitations and study at home.

If our pupils were to remain all day under the supervision of the teachers, and if at the end of our high school course we were to give examinations covering the whole four years of work and fail 60 per cent. of the candidates, if we were to push the high school graduate at once into his professional school and if we were to introduce into our high schools a military discipline we might achieve the same seriousness of purpose, strenuousness of effort and facility of recitation that marks the science work of the French lycées. But we might lose that spontaneity, vigor, originality and self-confidence which the American high school pupil possesses in marked degree as compared with the lycée pupil. The latter gives an amazingly good reproduction of the professor's lecture and handles mathematical physics in the lycée in a way that would put to shame the American college student, but when he is switched off the beaten trail of memoriter reproduction onto a problem where initiative and mental alertness are needed or into chemical or biological subject-matter he is below par on the basis of American standards. That is merely a personal opinion, but it is based on "assisting" at many classes in a number of French lycées. The American university student in European schools is struck—and on this point many were questioned—with the accuracy and range of information possessed by the European university man. He has memorized the content of his lycée and university courses in a surprising way, probably because he must do so to pass the final stiff examinations. In how far he has sacrificed intellectual astuteness and independent resourcefulness in its accomplishment it is hard to judge. The American is quite sure the educated Frenchman lacks our own ebullitional buoyancy, alertness and ability to tackle forcefully and efficiently the changing problems. Face to face with a new situation we are as nimble on our intellectual feet as the proverbial cat and are at it at once with glowing optimism born of self-reliance. They seem bound by tradition, inert and pessimistic.

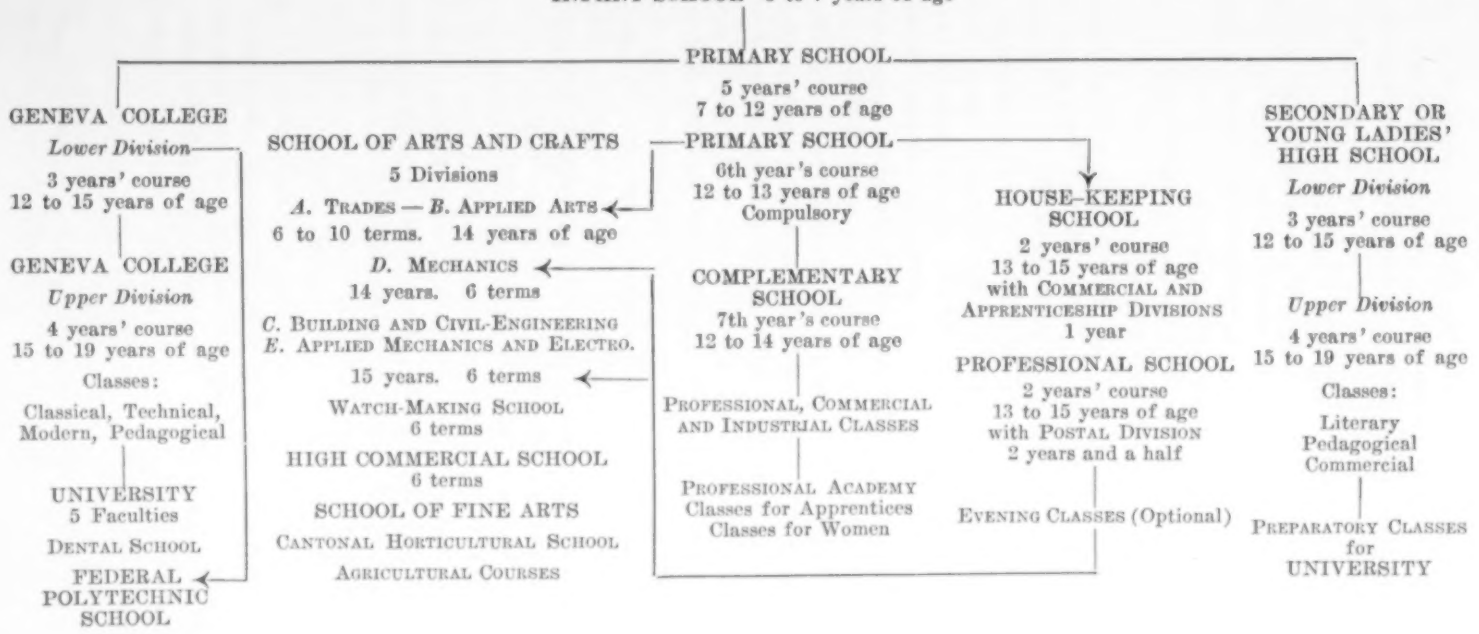
The preparation of the French teacher for his job is excellent as far as mastery of subject-matter is concerned. To teach in an elementary school he must have graduated from such a school or the corresponding primary school (equivalent to the completion of our fifth grade), he must have done two or three years' additional work

to prepare for the examination admitting to an elementary normal school from which he must graduate in a three-year course. The professor in a lycée is either a university graduate or else a graduate of one of the superior normal schools. In either case he will have done three years' work at least beyond his bachelor's degree, which it will be recalled he receives on graduation from the lycée. Entrance to the superior normal schools is by examination, which it is generally conceded is more difficult than the examination to the universities.

The work in the normal schools is largely subject-matter work given by men selected for their reputation as specialists and for their skill as teachers. There is in the elementary normal schools a brief course in general pedagogy and a year's required practice teaching, in which the candidate is under careful supervision and severe criticism. There is practice teaching also in the superior normal schools, except in the École Normale Superieure at Paris which, though aiming to be a teachers college, is rather, according to our standards, a university of high grade. Its faculty members are the most inspiring teachers in their several lines to be found, men who can stimulate research on the part of their students, who are in turn the most select group in France. The French normal school student is concerned first with the mastery of the subjects he is to teach, the art of teaching receives scant consideration except as he almost unconsciously copies the methods of his teachers, and the science of education is still quite below his horizon. The English normal schools (all private), devote much more time to pedagogy, and such courses are strong in the philosophy of education. The Modern Educators Library starts with a volume on "Education, its Data and First Principles" (Edward Arnold & Co., 1923) by T. P. Nunn, the brilliant director of the London Day Training College, which volume is saturated with it. The English are appreciative of our American attack on the problems of education by the experimental method, though they still stick largely to their philosophical and psychological approach. The French are largely unaware of American contributions along this line. The nearest approach to it encountered anywhere was in the Jean Jacques Rousseau Institute at Geneva, where Claparede is working along the lines of animal psychology that Thorndike traversed years ago, and Pierre Bovet, the director, is giving courses somewhat similar to Devine's at Columbia on sociological applications of education and studies of the delinquent boy. They are at least feeling their way into the scientific attack on educational problems and are conversant with the American results of such studies.

The French technical and trade schools are excellent and in

PLAN OF INSTRUCTION



them the science is taught by the laboratory method, *i.e.*, when the acquisition of skill comes to be important individual laboratory work is made a feature of the education. Such schools seemed to me at their best in Switzerland. They are not only efficient individually, but they are admirably interrelated and adjusted to the rest of the school system. The Swiss seem very apt in vocational guidance and pupils are directed into that phase of educational endeavor that seems best fitted to their needs and capacities. The scheme of the schools in Geneva, reproduced from "Geneva, an Educational Center," is given to show the numerous schools maintained by the canton and their interrelations.

Summarizing, I should say that elementary science is quite as commonly studied in grades one to five in this country, and is better done than in the corresponding grades of France, Switzerland and England. Physics in French lycées and the corresponding schools of Switzerland is much more thoroughly mastered, particularly in its mathematical phases than in our high schools, but our pupils certainly do as well as theirs in chemistry and much better in the biological sciences. Enrollment in science in the English secondary schools is very light, the work is poorly done, the equipment very meager. In the technical schools, especially in Switzerland, the science work is admirably done with excellent laboratory and shop equipment for individual work, and such schools are so related to the academic schools as to facilitate the movement of pupils into them in accordance with the pupils' aptitudes. Teachers of science as of other subjects are well prepared, as far as mastery of subject-matter is concerned, in excellent normal schools or in the universities, but the courses in pedagogy are short and elementary, and there is almost no scientific study of the problems of teaching. The French and Swiss universities are on a par with our own average state universities as far as teaching staff and equipment is concerned, but the buildings are often poorly adapted to educational purposes. There are no universities in these countries that compare with our great universities in point of buildings and equipment. The science work in the universities is very like that in our own schools.

THE VACUUM—THERE'S SOMETHING IN IT[1]

By Dr. W. R. WHITNEY

DIRECTOR, RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY

We humans want better minds, broader horizons and greater understanding. These scientists assembled here are all at work in their respective fields searching for new truth, to improve the process by which our minds, our horizons, our powers and our outlooks grow.

When, in the middle ages, the great cathedrals of the world were being built, the mentality of men seems to have been directed to systematic subordination of creation rather than to active appreciation of it; to acquiring salvation, or "safety first," rather than knowledge or understanding. To-day you scientists, in seeking truth, think of "safety first" last.

We are told that if the total age of mankind be expressed as the life of a man of fifty years, and if he then looks back upon his progress, he will see that what marks his greatest advancement are events occurring in the most recent years. For example, such a 50 year man now sees that he had not learned to scratch the simplest records on stone until his forty-ninth year. All the immense advantages of printing have only existed three months for him. He has only just learned how to pass along what he has learned. The uses of steam, which now seem so necessary, were acquired only three or four years ago. The uses of electricity (street cars, lamps and telephones), which did not actually begin until about 1880, arrived the day before yesterday to this 50 year mankind. The automobile, wireless, X-rays, radium and most of the things which occupy our interests to-day, were actually discovered on this particular fiftieth birthday.

The power outside of his own muscles, which during the past two or three months he has learned to control, has grown to nearly twenty horsepower, or one hundred manpower, for every man in the country. Therefore, it makes only one per cent. difference whether all the men work like horses or not. But *guidance* of power is man work, because there are no machine-mentalities. Almost everything but thinking may be artificially done, but knowledge and understanding must be actively sought and used. Man is the only animal that can do this.

[1] Address expanded by Dr. Whitney at the suggestion of the Editor, after its delivery as a talk illustrated by experiments before the joint public meeting of the American Association for the Advancement of Science and Sigma Xi at Cincinnati, December 29, 1923.

Scientists know that research merely discloses new parts of the infinite unknown. Paradoxically, the enticing, helpful "unknown" increases as men continue to subtract *from* it. Progress in every line of experimental science follows the same law. The apparently narrow path gradually expands into unlimited, unexplored territory. With his new tools and his increased speed of communication, man finds that he can advance into the unknown faster than his ancestors could, and children seem to learn more rapidly than he did when he was young. The scientists of the twentieth century are legion. But scientists were anathema a short time ago. There is to-day more chemistry in the atom than there was in all "inorganic" chemistry a few years ago. There is more in the "sugars" now than there was in all "organic" when I studied it. There is more immunity in blood and more heredity in the microscopic chromosome than there was in all biology until recently. There is more crystal structure research by X-rays now than research in all mineralogy when Agassiz came to America.

There is special reason for my bringing before this group of scientists such a narrow field as the vacuum. It seems desirable that the applications of new knowledge be continually distributed throughout the separate sciences. In fact, that is probably the main advantage of an association of this kind and of such meetings as to-night's. I want to show that in a vacuum, of which one might say, "There is nothing in it" (and surely less than in anything else), there is, indeed, an endless amount of interest and utility. The American public now buys over a million dollars worth of glass vacua a week, but that is the least interesting part of the subject.

Everybody pretends to know that "nature abhors a vacuum." But he who started that tale merely meant that a good vacuum was hard to produce. As probably no one has ever made a vacuum with less gas-molecules in a cubic inch than there are people in the world, we can maintain that perfection in vacua is still precluded by nature.

My object is to review some studies in vacua so as to create not only the impression that any one may well do research work there, but also certainly anywhere else with pleasure and profit.

We all know that we see at night largely by the aid of vacuum lamps. Through other vacuum lamps, called X-ray tubes, we also see through opaque bodies. The light which illumines our microscope specimen has its analogue in the X-ray light which shows us the crystal structure of matter and the electrical formulae of chemical atoms. Our transcontinental wired telephony is possible through vacuum tubes which, in various forms, also permit our wireless broadcasting and wireless reception from the most remote

stations. The workman who keeps his drink hot or cold in a thermos bottle is clearly indebted to Sir James Dewar's application of the vacuum, but the scientist is still more indebted to it. All our steam power plants, including turbines, owe their success to vacua.

The latest arrival in the family of the chemical elements (hafnium) was discovered by trying it in vacua as an X-ray target. Our list of possible chemical elements was rounded off by Moseley's study of the X-ray spectra just in time to meet the wonderful discoveries of J. J. Thomson and Aston, all made in vacua. The latter showed that most of the elements, supposedly simple, are still mixtures of two or more similar elements (isotopes), while Professor Thomson's experiments disclosed by the positive ray method a whole series of new atomic compounds.

While the vacuum was not essential to the work of Millikan in isolation of the electron, yet the earlier work by Thomson and others, and much of the recent work on this ultimate constituent of matter, has been necessarily carried out in vacuum. To-day there seems to be no end to the studies which can be based on the fact that an atom or molecule of material may be separated electrically into a positively charged ion (carrying most of the mass) and a negatively charged electron (carrying most of the current).

Electricity

I may not be sacrificing historical truth too much if I claim that electricity at rest was the first kind known. This may be wrong from many points of view, but I wish to assume it. It then seems logical that electricity in simple direct motion should later appear and that still later we should find various directions and rates of its motion, if it moves at all. It will interrupt this line of argument if we doubt the existence of electricity as a thing, or question the existence of such different kinds of it as static and dynamic. The electricity of rubbed amber was the first and stationary kind (if you will admit that prior to Thales such things as lightning were something else). When the electricity first moved through metals the process was looked upon as a simple directed flow which proceeded until the charged body had delivered its charge.

Currents

This direct flow of electricity (a current) was strengthened in its hold on our conception by the great number of different chemical current-producers which followed the controversies between Galvani and Volta a century and a quarter ago. Primary and secondary or storage batteries without number were soon dis-

covered. The current from such batteries was exactly like that which the magneto electric machines produced, when these were developed, after Faraday had shown the effect of moving a wire through a magnetic field.

The direct current of such generating machines was much later followed by the alternated flow, and soon alternating current generators were made for different rates of reversal of direction. Sixty, forty and twenty-five cycle currents are now common and the user takes his choice. These frequencies were once accidents of convenience and economy. For some uses other widely different frequencies of alternation are very desirable, as in wireless, where 100,000 cycles are common.

Now the phenomena which have been found in vacuum tubes promise to give complete control over all these details of kind and frequency of current.

Electrical Control

As will be more fully shown later, when a unidirectional current meets vacuum tubes as though it would pass through them, it must find one particular kind of a tube, and the current's direction must be right, because some tubes will let it through only when it is both unidirectional and in the proper direction. These in themselves are rather remarkable things to expect of a vacuum, but as usual, the truth exceeds the expectation.

Catalysis

To give some idea of the extent to which vacuum studies may affect remote fields, let me mention chemical catalysis, the secret of most reactions of life. For example, it is known that mercury vapor in a vacuum, when illumined by light of a certain wave length, will absorb that light and turn the energy over to hydrogen, if hydrogen be present, so that this, in turn, will chemically reduce such substances as cold copper oxide. Here is a new kind of chemical process. It is the kind we have needed in order to begin to explain some of those life-reactions which vegetation discloses. That is, similar facts will probably be found to contain the explanation of the catalytic action of sunlight on growing plants.

And so the studies of phenomena in vacua may lead us into the most widely separated fields. The experiments which I have chosen for this evening are illustrations of this fact, and you must not, therefore, expect them to be very closely related.

Kinds of Vacua

I might say, as in our school-day essays, "there are different kinds of vacuum too numerous to mention" and then proceed to

mention them all, but I will merely illustrate several cases. A certain kind of vacuum is good enough for incandescent lamps because other factors besides the quality of its vacuum determine the death, or limit the performance of a lamp. But while formerly the incandescent lamp represented the very highest skill then reached in vacuum production, there are now other commercial vacua which are necessarily quite superior. This is true of good thermos bottles, X-ray tubes, radiotrons and other wireless tubes.

We should first, therefore, give brief consideration to the incandescent lamp, and note a few characteristics. Its low vacuum early disclosed electric cross-currents which would not have been found in much higher vacua. Study of these currents has led to the vacuum tubes used in wireless, and also to such remote disclosures as that distillation or evaporation of solids in vacuo proceeds in straight lines. The electrical currents in poor vacua are best known in luminous Geissler tubes, Moore tubes and Claude tubes, as seen on the streets of Paris, for example. They are themselves a large subject, but I will consider later on only one historically important experiment with them, the Hittorf experiment.

High Vacua

Electric currents through vacua where gas is so completely removed that it has no appreciable action are more strictly a part of my present paper. After the work by which the individual and indivisible negative electrical charge or electron was defined, it seemed quite fitting, though unexpected, to learn that these negative charges were exuded by hot bodies. The result of this disclosure formed the basis for most of the modern electrical phenomena in vacua. The activities of electrons are apparently the cause of most electrical and chemical processes. Their motions constitute electric currents and the currents are determined and controlled by voltage or potential difference.

Bees might illustrate electronics, though it's admittedly bad policy to push bees too hard. If bees represent electrons, then matter in general becomes the hives. When the hives are cold or in the dark the bees stay inside. Under the effect of heat or light the bees are induced to come out. Similarly, highly heated matter, such as tungsten, exudes electrons, and at ordinary temperatures light induces electrons out of metallic potassium, for example.

What are the bees or electrons going to do after they are out of the hive (or the metal)? That depends on impulse or pressure. They will fly in that special direction which tends to relieve that particular pressure. They proceed down the gradient. The electrons coming out of the metal (because of heat or light) will also

fly in that special direction which will tend to relieve the particular electrical pressure. They also proceed down the gradient. But if there is no particular impulse or gradient both bees and electrons hang around the source.

A lot of electrons, like bees, flying in a common direction, become a current or cathode ray. We might let them fly from the hot or lighted spot into a cold or dark one and until we heated or lit up the latter they would not come out. This unidirectional current corresponds to what takes place in rectifiers and kenotrons where we have impulses in the two opposite directions but one hot and one cold electrode in vacuo. If both hives (or both electrodes) are equal in temperature or illumination, no differential in current is possible, and with alternating impulses alternating instead of pulsating direct current passes. Thus bees illustrate two-electrode vacuum devices.

In the three-electrode vacuum tubes the third electrode is a sort of grid, or open fence, located between the hot and cold electrodes. This grid lets electrons pass freely except when it is negatively charged. Thus also the bees would pass through a wire fence when they might be stopped if their impulse to proceed could be suddenly removed there. The negative charge is used in the three-element tube to alter the intention of the migrating bees or electrons as often as desired, and this with the rapidity of light.

In the case of "wireless" it is the impulse from the antenna or loop, changing with every delicate change of voice-current or code-current, which, when led to the grid, charges it and thus controls the currents within the receiving tube. These controlled currents do the work in the telephone.

Everybody knows that wireless tubes are very sensitive. One cat-power of electricity used in New York actually puts the impulses into a wireless outfit in San Francisco, and at the same time it also puts the identical impulses into millions of other receivers. But some appreciable energy must be used by each receiver to direct the local battery which operates the head sets. This minute quantity of energy has been made significant as follows:

If a house-fly climbs up a window pane one inch he does a definite amount of work in lifting his body that much. If this work constituted the supply fed into the wireless tube from space it would suffice continually to actuate the outfit for a quarter of a century. This might interest a future student of telepathy, if the time comes to determine how far the energy of one thought may influence thought in a distant brain. It has not been possible thus far to determine the quantity of energy which is expanded in thought. Just keeping alive transfers so much energy into heat

that the additional energy transferred, when we think, has been too small to detect. But it need not be small compared to the power sensitivity of a wireless set.

Vacuum Tubes

Before showing the tubes I will briefly summarize them. The mere names of these modern applications of electrons in vacua are legion. The kenotron is a vacuum tube which changes high voltages alternating into direct current, and it has its counterpart for low voltages in the battery-charging tungar rectifier and the mercury rectifier. The various radiotrons, receivers and amplifiers of wireless are also the most direct applications of the action of negative electrons in good vacua. But X-ray tubes must also be considered in this connection, because X-rays are the result of the "bump," if you will, of rapidly moving electrons in vacua against the atoms of matter.

Electrons in motion are also directed and controlled by electromagnetic, as well as by electrostatic fields. Therefore, the magnetron and axiotron have to be shown or referred to. Because the mere illumination of such metals as potassium (like the high heating of other metals, such as platinum and tungsten) causes them to emit electrons, the photo-electric cell has to be included in our illustrations.

The electrons within the vacuum, as in a wireless detector tube, obey the inconceivably feeble electrical impulses received by the antenna. Conversely, the motion of electrons sets up impulses and waves in space. In other words, the vacuum detector may be made a wireless wave generator. They are used in most broadcasting stations.

Ether Waves

The wave lengths of the magnetic waves produced by the changes of motion of the electrons are very long in case of wireless (say 100–10,000 feet), millions of times shorter in ordinary light and millions of times shorter still in X-rays, but they are all in the same medium and all due to motions of electrons.

High Frequency

The induction effect of currents themselves is nothing new. Motors and generators depend on it, but the production of very high frequency currents is a recent result of vacuum tube development and so is part of our subject.

Special Emissions

Finally, to give an impression of the distance such work has gone, I have also added the case of a one-atom deep layer of thorium on tungsten in a vacuum and its effect on electron emission.

THORIUM EMISSION APPARATUS

In order to illustrate several of these vacuum phenomena simultaneously the Hewlett loud speaker is made part of the address. Microphonic currents are carried to one vacuum device or receiver and this acts in turn upon others as amplifiers. Telephone currents of large magnitude carrying the characteristics of the voice are thus produced and conducted through flat spiral coils close to and on both sides of a thin metal plate whose vibrating motion transfers to the air powerful sound waves corresponding to the original voice. This plate has to be subjected at the same time to induced currents from a direct current which is produced from the city alternating current by several vacuum kenotrons, as will be described.

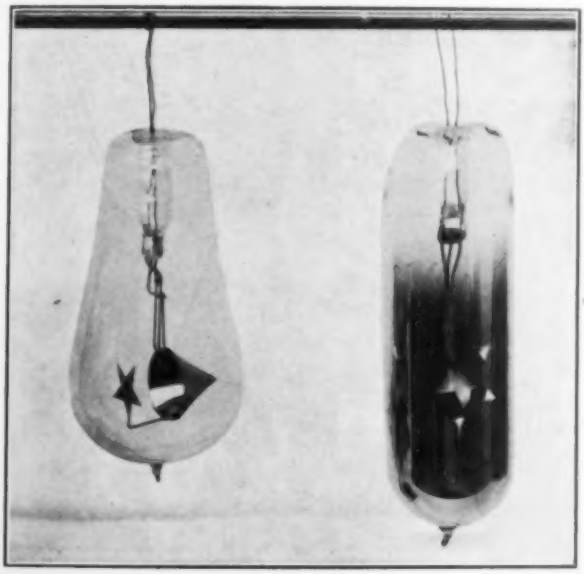
LAMPS

Now for some experiments. The first great use of vacuum was in incandescent lamps. I burn out an ordinary tungsten lamp by raising its voltage very much above normal. It lasts for a few minutes only, but it gives a light perhaps five times as efficient as we usually see. The lamp dies because the tungsten vaporizes or melts. The vacuum is not at fault. It is because of these limita-

tions that commercial lamps are so made that they burn at normal voltages on proper circuits an average of one thousand hours. If we were satisfied with a shorter life we could have a more efficient light, but experience has shown that we would be unwilling to submit to short life lamps in order to have the added efficiency. To lengthen the life of lamps much study has been made of distillation of metals in vacua, and of methods for returning the distilled metal to the filament. Much has also been done to make the deposit on the glass invisible or white, so as not to interfere with light transmission. Naturally, we are always on the lookout for metals, such as the newly discovered hafnium, which might possibly live longer as filament than tungsten now lives. Thirty or forty years of research work had been spent on high vacuum incandescent lamps before Dr. Langmuir showed us how to make still better lamps by putting back into the vacuum gases like argon and nitrogen.

Distillation

When the material of a filament distills in vacua it does not meet interference to the motion of its molecules, and the distilling substance proceeds in straight lines from the heated source. This is often observed when an incandescent vacuum lamp arcs or burns out. Metal shadows of interior parts of the lamp are then often cast onto the walls. This is shown more clearly when a metal like gold is evaporated from the surface of a tungsten filament in



Vacuum Distillation

vacuum. By interposing a design (in this case a star) the shadow in gold was cast on the glass. This simple phenomenon is mentioned because it fits in with the kinetic theory of gases and explains many things observed in vacua. The "mean free path" of molecules or atoms is very long in good vacua, and so straight line distillation occurs.

Hittorf

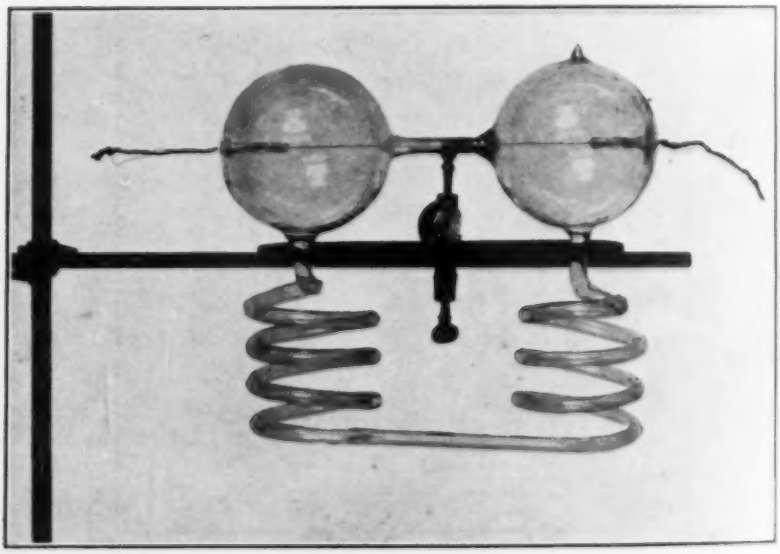
In the historic Hittorf experiment two vacuum bulbs, each carrying an electrode, were joined together by two glass tubes, one very short and one exceedingly long. When electric current was passed from one bulb to the other, it evidently chose the longer instead of the shorter path, because the longer tube became highly luminous, while the shorter one did not. This is a quality of electrical conduction in vacua where small quantities of gases still remain, but it can not be gone into here.

Edison Effect

The historic Edison effect was discussed and its relationship to pure thermionic currents shown. Where it was once thought that nearly visible particles of the filament were shot across the space between filament legs in vacua, now we recognize in very high vacua only the unidirectional motion of negative electrons.

Rectifiers

In vacuum tubes like the kenotron these electrons pass from the

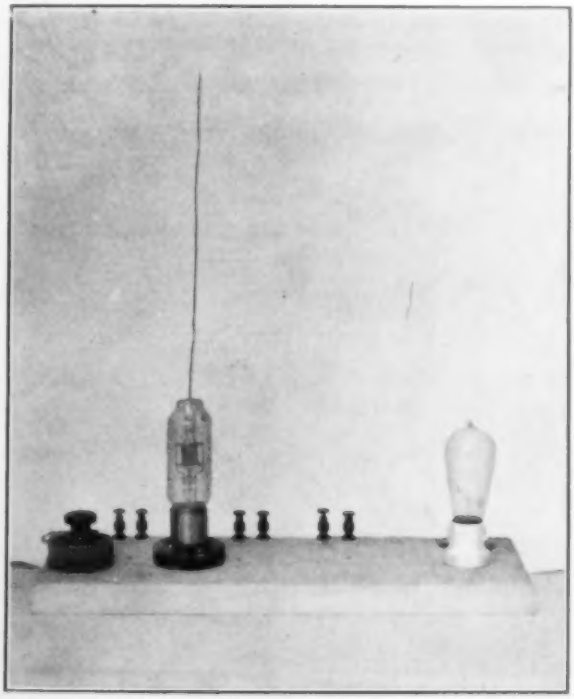


Hittorf Tube

hot filament to an electrode commonly called the "plate." This pure emission current is the basis for the so-called rectifiers because only when the filament is negative does any current flow across the space. When gases are present greater currents may be carried, because by the ionization of the gases the moving electrons produce new conductors from the gas molecules. Thus the tungar rectifiers, containing a little argon and the older mercury vapor rectifiers, involve the same principle. Without some gas present the negative electrons, by their very concentration, constitute a space charge which limits the current. This space charge is removed by the ions produced within the gas when present.

Radiotrons

When we interpose a grid or wire screen between the hot filament and the plate of the two-electrode tube or rectifier, we have what we now so commonly use in wireless for receiving, for amplifying and for production of high frequency currents. The discovery of the controlling or triggering action of the third or intermediate electrode was made by De Forest. A negative charge applied to this electrode or grid interrupts or modifies the electron stream, the current, from the hot filament to the plate. As it takes

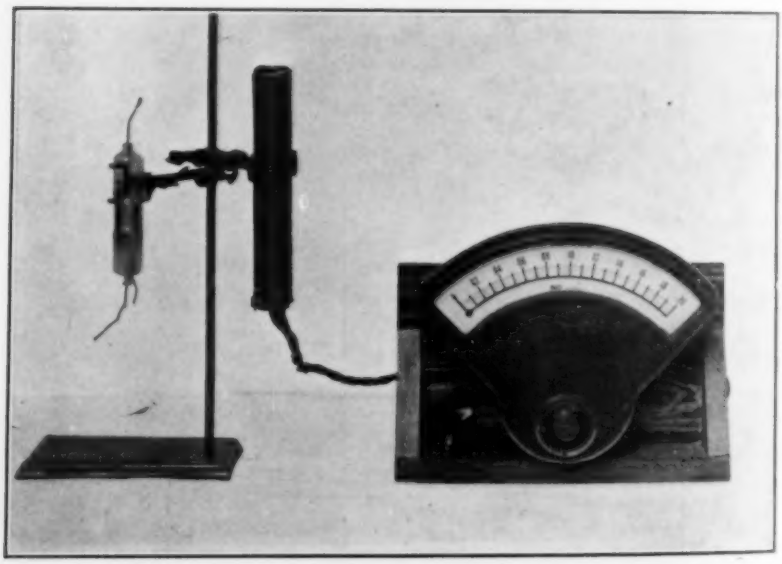


Radiotron Principle

almost no energy to charge this grid (little more than a "token" of energy, voltage), the slight power from a wireless antenna in its fluctuation may be used to control or to trigger, or to let through corresponding jolts of greater energy, which are in turn supplied by some local battery. In the experiment shown, an ordinary incandescent lamp was lighted by current which was passing through a three-electrode tube from hot filament to plate. Its light indicated this current. The grid, or antenna-wire, was sticking up from the tube so that it could "pick up" electric charges from space. A small negative charge was produced on a rod of insulating material by merely rubbing it with a piece of paper. The charge so produced caused the lamp to go out, or light up, as the charged rod was brought near to or removed from the exposed end of the grid wire.

Magnetron

As the negatively charged grid cuts off the current of the three-element tube, so an external magnetic field will also do it in the two-element tube, by so influencing or directing the moving electrons that they can not reach the plate. Such a device, called a magnetron, was shown. This particular magnetron, consisting of a cylindrical plate in a vacuum and a central filament within it, had a coil of wire wound on the outside of the glass. A feeble current was sent through the coil from a battery. A magnetic field produced within the coil by this current was intentionally made about equal to that



Magnetron

of the earth's magnetic field, so that by moving the whole apparatus about in space (thereby at one time adding to the earth's field, at others opposing it), the magnitude and direction of the earth's magnetic field could be disclosed by a meter which indicated the resultant current. When the magnetron pointed towards the north pole, the meter showed no current, while in other positions currents were measured.

Axiotron

Another useful vacuum tube of this type is one in which the magnetic field of the filament current itself becomes great enough during each current cycle to deflect the electrons so that they will not reach the plate. By this tube, "the axiotron," the frequency of an alternating current may be doubled or direct current be changed into alternating.

Photo-Electric Cell

Another vacuum tube is the photo-electric cell. One of these was shown connected with a relay to a lamp so that when light shone upon the cell, the burning electric lamp was extinguished, and was relighted on cutting off light from the photo-electric cell. In other words, it turns on the lights when it is dark, and turns them off when it is light. This depends on the fact that some metals like potassium emit electrons when light falls upon them. These electrons in vacua constitute a current when they are made to move by the electrical impulse. To repeat, applying potential

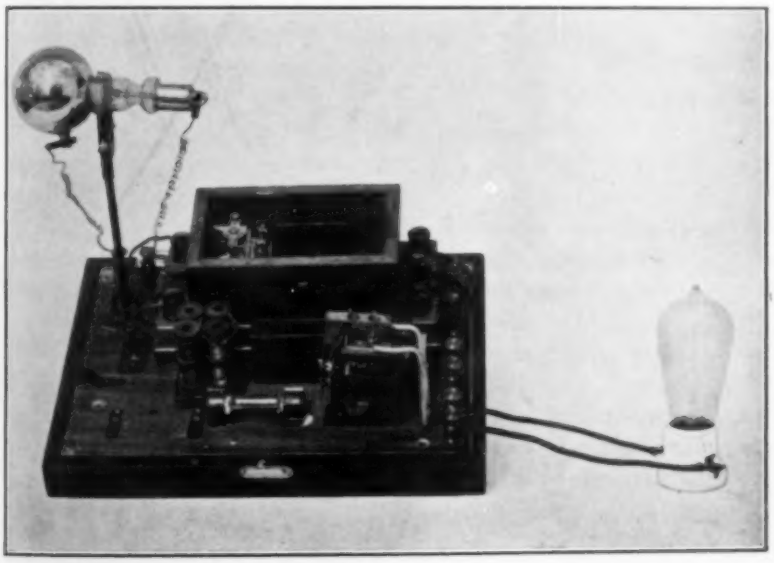
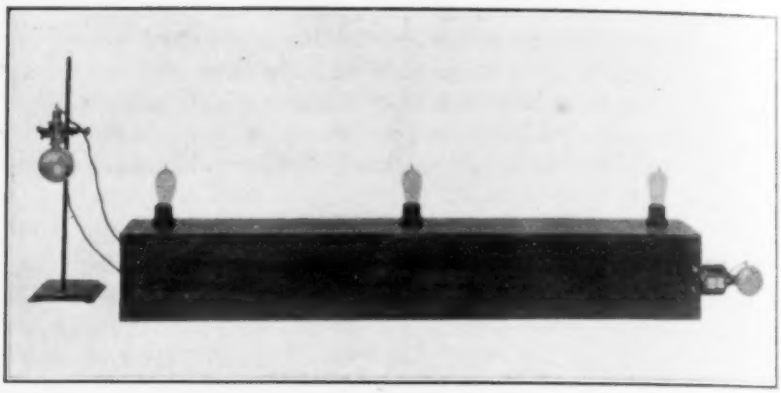


Photo-Electric Cell



THE NERVE

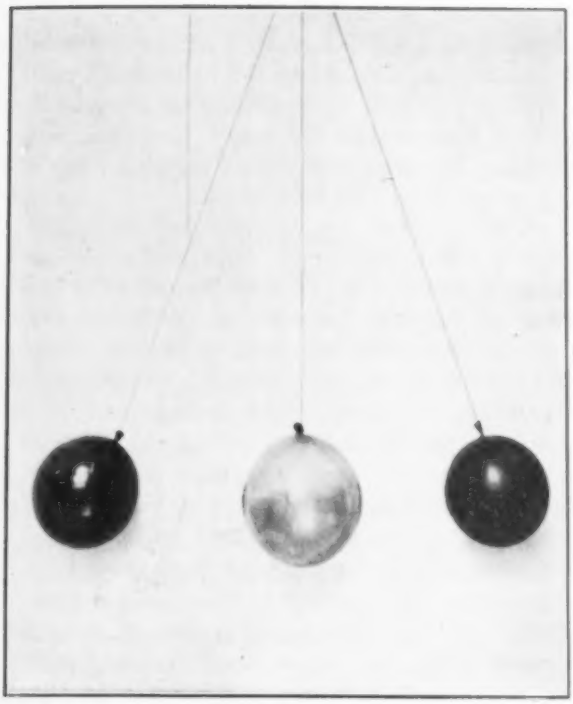
to a vacuum tube having a potassium electrode and another electrode for leading off the current causes current to flow as negative electrons from the illumined metal, and this current actuates the electrical switch which turns off the lighting current of the burning lamp.

THE NERVE

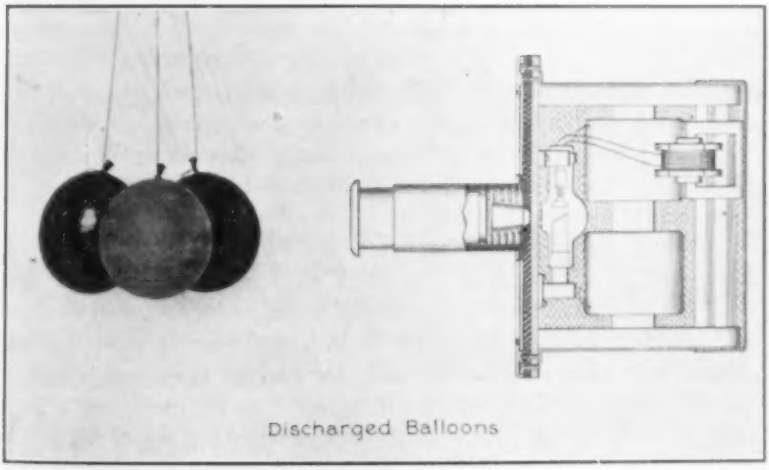
This led to the next, an ambitious physiological experiment. A photo-electric cell was made to represent a crude "eye" which was connected to a so-called "nerve" leading to a "brain." The nerve was merely a long box having electrical capacities and suitable amplifiers or three-electrode tubes within. The capacities served to slow down the apparent rate of flow of the feeble current from the artificial eye so that indicating lamps along the top of the box or "nerve" would light up, one after another, as the impulse from the "eye" passed along that path, or the nerve. After the last lamp was thus lighted by these amplified currents an electric bell rang to indicate reception at the "brain"-end of the circuit. This was not shown as a reliable replica of the real nervous system, but as an application of the vacuum tube which amplified the slight energy available and necessary for the experiment. With such slight energy it became practicable to show the delayed transmission and reception which is necessary for an illustration of nerve action. Nerve impulses travel much slower than electricity usually does, and this slow speed was one objection to visualizing nerves as electrical conductors until Crehore and Williams showed that nerves might be naturally so constructed as to transmit slowly.

X-RAYS

In order to show another vacuum product (the X-ray tube) an effect of X-rays was demonstrated which is not usually thought of



CHARGED BALLOONS



DISCHARGED BALLOONS

in connection with X-rays. Three rubber balloons, suspended close together by long cords, were first charged electrically by being rubbed on the head of the speaker. They then repelled each other

and stood stationary in space as at the corners of a large triangle. As soon, however, as a feeble beam of X-rays was projected towards them they quickly discharged and fell to their original position in contact with one another. X-rays ionize air or make it conducting so that the balloons could not retain their mutually repelling charges. This is the basis of a method for measuring the intensity of beams of X-rays.

Spectra

References were made to the various applications of X-rays, as in the study of internal structure of crystalline chemical compounds and elements. Cathode rays, currents of negative ions in vacuo when speeded up by high voltage, produce by their impact X-rays which are characteristic of the material on which they impinge; one may say characteristic of the mass of the atom of the substance of the target. It is through this fact that the X-ray spectra of the elements considered as to wave lengths are arranged in the same order as the atomic masses in the periodic table of Mendelejeff, and by this very method the newest known element, hafnium, has been recently added to the known metals. Referring again to our bee analogy, let a fast-flying swarm strike bells so hard that they make them ring. From the sound of muscial notes we guess roughly the sizes of the bells. We could thus place them in their musical series. The sound corresponds to the X-rays produced when the bees are electrons of cathode rays and sound waves are ether waves. The mass of the bell is disclosed by the tone or frequency; the mass of the atom, by the same sign, is disclosed by the ether wave-frequency. When a certain mineral was used as a surface for the electrons to hit, a new musical note in the ether was found. It was recorded photographically. Its place in the scale of elements had been predicted as accurately as middle C on the piano might have been predicted if it had never been heard.

With higher voltages the velocity of the cathode rays (or electrons) always increases. In the X-rays thus far produced, however, the penetration or transparency is practically limited to about a quarter of an inch of lead. It is interesting to note that the similar rays from radium, the so-called gamma rays, can penetrate nearly a foot of lead. This corresponds to an exceedingly high electromotive force. Thus radium rays (gamma rays) might be made in vacuum X-ray tubes if millions of volts were applied.

Atom Layers

An apparatus was shown, devised by Dr. Hull, which is essentially a two-electrode vacuum tube, the tungsten filament having

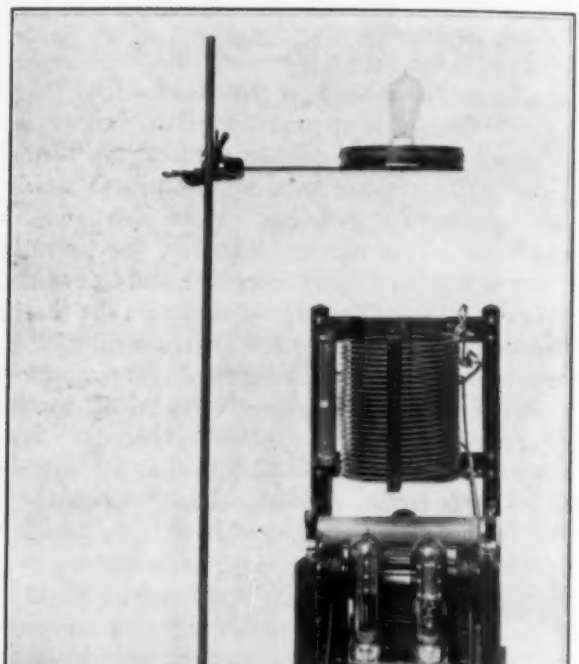
a little thorium in it. At a certain very high temperature this thorium rapidly diffuses to the filament surface. This thorium surface then has the peculiar power of emitting electrons a hundred thousand times as rapidly as pure tungsten at the same temperature. An ordinary lamp was lighted in this experiment by letting this thorium electron-emission current flow throughout the lamp filament. The vacuum tube containing the thorium-coated tungsten also contained a little gas. When the lighted lamp was short-circuited for an instant by a switch, the potential on the vacuum tube was thereby greatly increased, and this caused positive ion bombardment of the filament and thus tore the thorium all off the tungsten surface so that very few electrons were being emitted, *i.e.*, those characteristics of pure tungsten at that temperature. Then the load (the lamp) could no longer be "carried" by the electron current. To repeat, the heavy positively charged gas ions under the impulse of the raised electrical potential act like a powerful sand blast and effectively clean the thorium from the tungsten, thus greatly reducing the emission current. By highly reheating the filament for a few seconds only, a fresh layer of thorium diffused anew to the surface of the filament from within the tungsten, so that, then, at the previous lower temperature the load or lighting current for the lamp was carried as before by electrons emitted from the thorium surface. This was mentioned as a proof of the production of a layer of thorium on the tungsten only one atom deep. The electron current from thorium on tungsten is greater than from pure tungsten and also than pure or massive thorium and is maximum when the single atom layer is present. This is confirmed by experiments on partial recovery of the surface and supported by thousands of successive repetitions of this experiment on one filament.

High Frequency

The production of high frequency current by means of pliotrons was shown and an ordinary incandescent lamp was lighted by being brought within a foot of a coil which was carrying the current of several million cycles. This was said to be about as near to wireless transmission of power as we now have. This high frequency principle is also being used by Professor Northrup of Princeton for special electric furnaces. In these, the induced currents in the material of the crucibles or the material to be heated generate high temperature through local resistance.

Loud Speaker

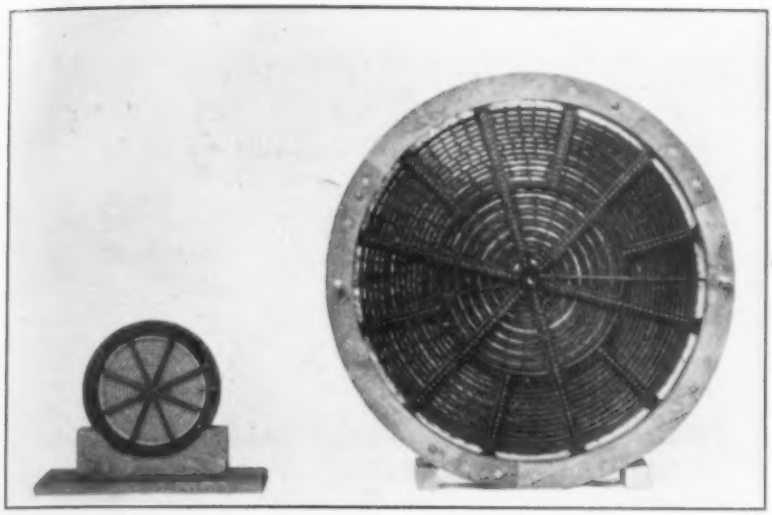
During part of the address a loud speaker devised by Dr. Hewlett was in use. This consisted of a 26-inch flat conducting disc in



HIGH FREQUENCY OUTFIT

a magnetic field. The vibrations of the disc corresponding to the voice currents produced the sound waves without the intervention of a horn. The use of vacuum tubes in this device consisted in the following:

A microphone was placed near the speaker and the sound waves of his voice caused to be generated in this microphone feeble electromotive forces which were applied to the grid of a pliotron. These feeble electromotive forces caused relatively large variations in the electric current flowing between filament and plate, which in turn were used to secure larger electromotive forces to be applied to the grid of another pliotron. By the use of several amplifying pliotrons the original feeble electrical currents were multiplied several thousand times and supplied to the loud speaker which reproduced the original sounds with many times the original volume and great faithfulness of quality. To operate this amplifier of pliotrons required a direct current of several hundred volts. This was obtained by first transforming the power from the ordinary alter-



HEWLETT LOUD SPEAKER

nating current lighting circuit to a relatively high voltage, next rectifying this high voltage alternating current by means of kenotrons, and finally smoothing out this pulsating current by means of appropriate electric circuits.

The high degree of faithfulness of reproduction realized in this loud speaker is due partly to the absence of a horn, eliminating horn resonance (one of the usual sources of distortion in a speech reproducer), and partly to the method of vibrating the diaphragm by forces which are distributed fairly uniformly over its surface, instead of being acted upon in a very limited region, as is the case in most other loud speakers. This feature eliminates rattling and ringing of the diaphragm or the production of high overtones by the diaphragm vibrating in its partial modes.

ERNEST FOX NICHOLS

The distinguished physicist, director of research in the Nela Laboratory, Cleveland, who died on April 29, while reading a paper before the National Academy of Sciences

THE PROGRESS OF SCIENCE

By Dr. EDWIN E. SLOSSON
SCIENCE SERVICE, WASHINGTON

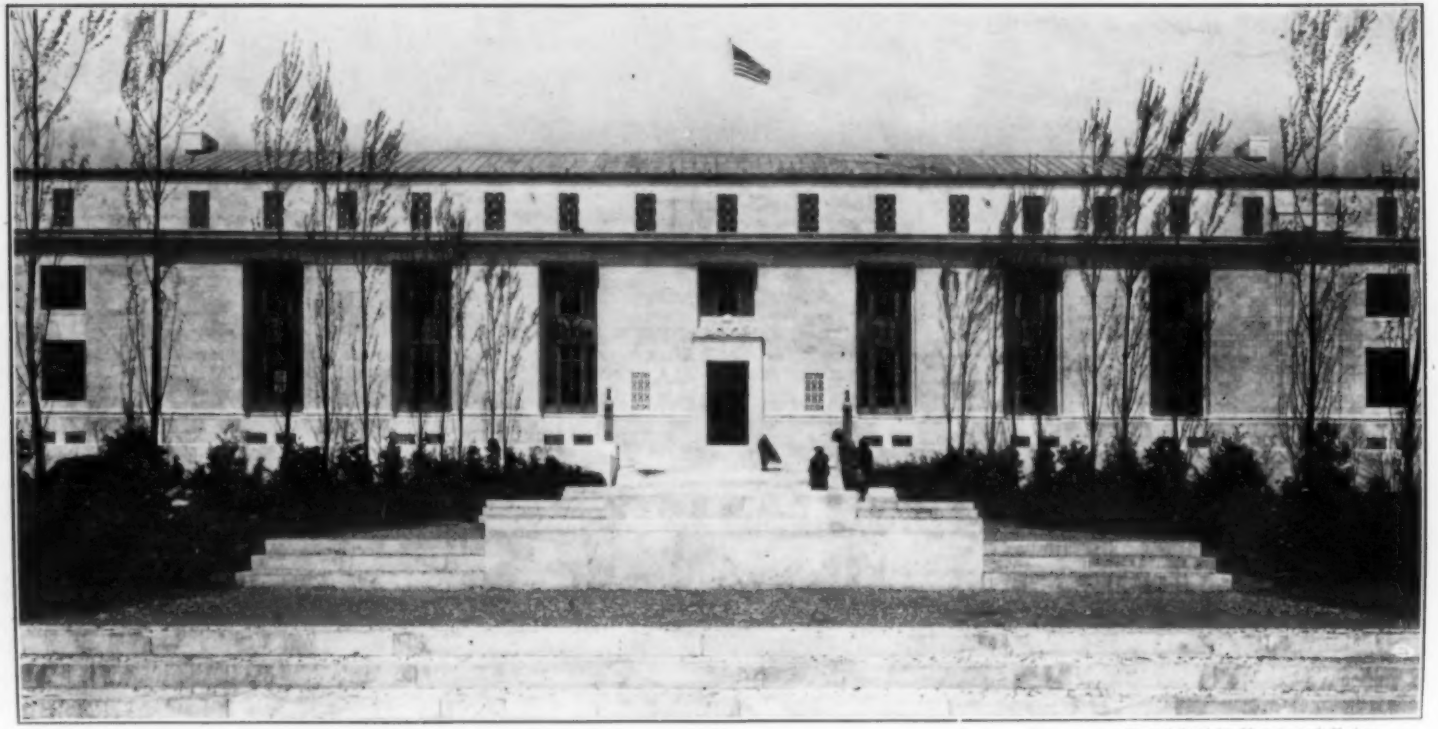
ERNEST FOX NICHOLS

At the moment when he was completing his demonstration of new radio waves on April 29, Ernest Fox Nichols fell back upon the exedra in the rotunda of the new building of the National Academy of Sciences. His wife rushed to his side with restoratives, but in vain, for a few minutes later, President Michelson announced his death, and the adjournment of the session of the academy. Shortly after, the academicians were walking in procession down the marble steps through the newly planted garden following the body of their distinguished colleague.

Professor Nichols had died as he had lived, in the active promotion of science. Research was his life work, and although he had twice been tempted into administrative office, by serving as president of Dartmouth College from 1909 to 1916, and by accepting an appointment to the presidency of the Massachusetts Institute of Technology in 1921, he gladly returned again to his investigation of the laws of light.

Visible evidence of his ability as an experimenter was close at hand, for while he was yet speaking visitors in a room next to the rotunda were examining the apparatus with which he proved the pressure of light. By touching a button of this ingenious mechanism, one can turn on an electric lamp and actually see for himself that the beam of light exerts a definite pressure upon whatever object it strikes. This pressure is so minute that it had never been observed until Professor Nichols demonstrated it twenty-four years ago. Yet as we now know the sunlight falling daily upon the earth amounts to a weight of more than 100,000 tons. It is this light pressure that makes the tail of a comet by driving the infinitesimal dust particles away from the sun. It is also light pressure that keeps the gaseous stars like Betelgeuse swelled out to their gigantic size in opposition to the attraction of gravitation tending to draw them together into a solid mass. The actual demonstration of the fact that light produced a pressure effect was of especial importance, since it is involved both in Maxwell's theory of the similarity of electrical and light waves and also in Einstein's more recent theory of relativity.

The life of Ernest Fox Nichols was cut short at fifty-five, yet few of his elder colleagues in American science have accomplished more. He was born in Leavenworth, Kansas, and being early left an orphan, was brought up by his uncle, General Fox. He went first to the Agricultural College at Manhattan, Kansas, and afterwards studied at Cornell, Cambridge and Berlin. At Berlin University, under Professor Rubens, he began his work on the long wave lengths about which he was talking when he died. While professor of physics at Dartmouth, he developed a radiometer of such delicacy that he was able to measure the heat that comes to us from the stars. In his last paper he was engaged in closing the "missing link" between the longest of the heat waves and the shortest of the radio waves, thus completing the series of the spectrum which runs from the "gamma



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FAÇADE OF THE NEW BUILDING OF THE NATIONAL ACADEMY OF SCIENCES AND OF THE NATIONAL RESEARCH COUNCIL, DEDICATED AT WASHINGTON ON APRIL 28

rays" of radium, which are a hundred thousand times shorter than light waves, to the "wireless waves" which are miles in length.

It would seem almost that he had a premonition that he would not complete his paper, for he began by saying that he would reverse the usual order of procedure and present his conclusions at the beginning. So he showed his last slide first. His auditors assumed that he did this in order to avoid being interrupted by the president before he had completed his demonstration, as speakers often are. His paper was, indeed, left unfinished as he feared, but it was a higher power than the president of the academy who notified him of the expiration of his allotted time.

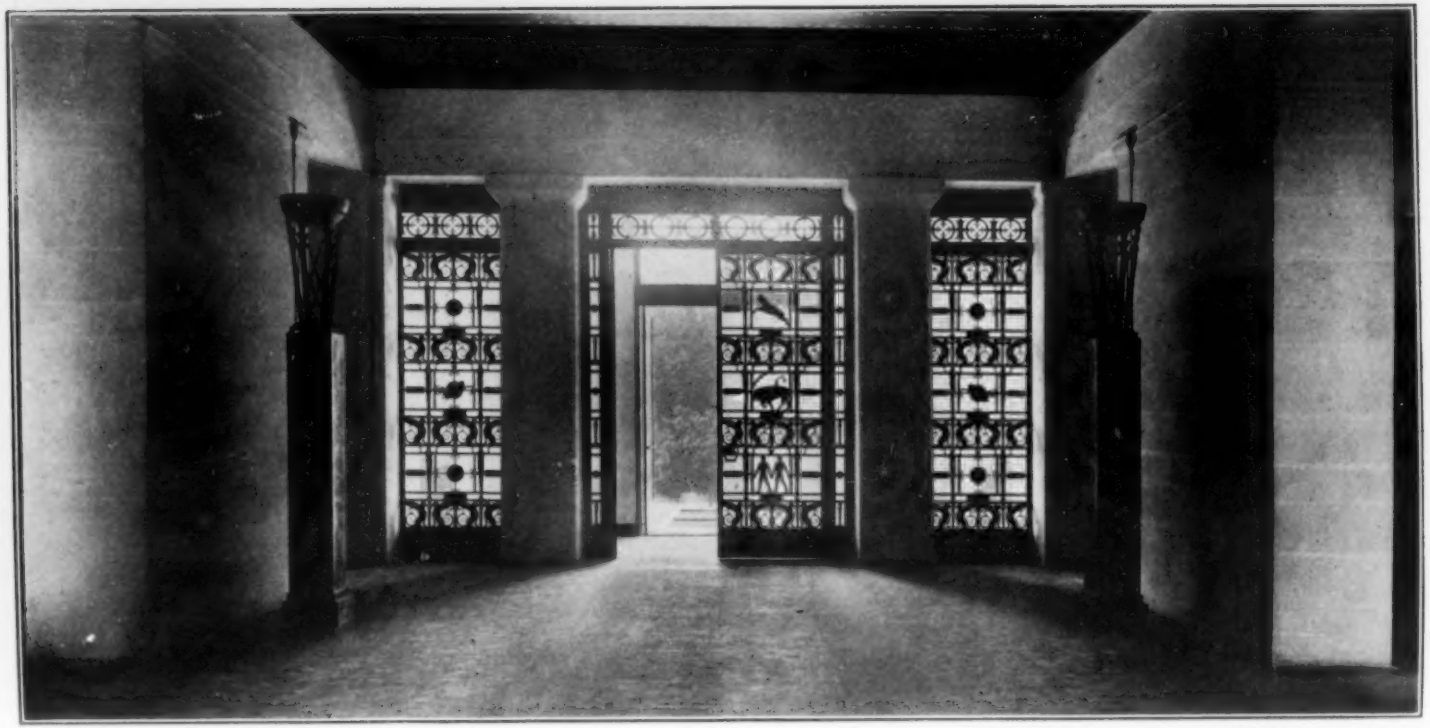
A LACTIC ACID THEORY OF THE UNIVERSE

We know that chemistry plays an important part in modern industry. We know that certain chemical substances in minute amount, such as the hormones that naturally exist in our bodies and the drugs that we unnaturally put into our bodies, have an effect upon our health and temperament. I wonder if we can not go farther and inquire if our metaphysical notions may not also be traced back to chemical causes. How, for instance, do we get our abstract ideas of space and time which form the framework of the external world?

Our concept of space seems to be founded primarily upon the movement of our muscles. It requires more of an effort to reach a yard than to reach a foot. We get more tired in walking two miles than in walking one. Of course it does not always require the same effort to cover a given distance with the arm or by the legs, but the relation is much more constant than the data given by the sense of sight, where objects change their shape and size quickly, as we or they move about, in a way that must be most perplexing to a baby. Even yet we may be deceived by our eyes and mistake a bush on the next hill for a tree on the horizon. Our sense for sound is still more unreliable. So we fall back for substantiation and verification of extent and distance on some sort of muscular exertion. We measure space by our feeling of fatigue. It is much the same with our sense of the lapse of time. Two hours' work seems longer than one. Though time seems to go faster or slower, depending on whether our employment is enjoyable or distasteful, yet we average it up in the long run as we do our spatial estimates, and consider space and time objectively as constant.

Now what is the cause of the feeling of fatigue on which we base our ideas of extension and duration? It is evidently dependent in some way upon the accumulation of the waste products of muscular exertion, such as lactic acid. "The fatigue maximum is associated with the lactic acid content in the muscle."[1] "The rate at which lactic acid is produced almost certainly varies directly with the activity of the muscles."[2] A minute and a half of violent exercise has been found to increase the percentage of lactic acid in a sample of the blood, taken twelve minutes afterwards nearly five times, not counting the much larger quantity that had been oxidized.[3] A man weighing 150 pounds may by exercise produce 3.5 ounces of lactic acid. "The exhaustion following long-continued moderate exercise is due to the diffusion of lactic acid out of the muscles where it is slowly oxidized and removed."[4] Whenever we exercise a muscle lactic acid is pro-

[1] *Chemical Abstracts* 16, 2545 (1922); 17, 816 (1923).
[2] Bainbridge, "Physiology of Muscular Exercise."
[3] *Chemical Abstracts* 17, 3532 (1923).
[4] *Ibid.*, 15, 2311 (1921).



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ENTRANCE HALL TO THE BUILDING OF THE NATIONAL ACADEMY OF SCIENCES

duced in proportion to the exertion and when the lactic acid is made more rapidly than it can be carried off by the blood and consumed we get the sensation of fatigue. So our measure of space is somewhat dependent upon the amount of lactic acid in the body.

If this argument does not convince the reader, I may approach it in another way. Our only knowledge of space comes from our exploration of it by movements of limbs or body. A spherical and stationary amoeba, a mere drop of jelly, can not be considered as having any conception of spatial extent. When a little lactic acid accumulates on the surface of the amoeba the protoplasmic granules at that point absorb water from other parts of the organism by imbibition. This produces a pseudopodium, or extempore limb, with which the amoeba may reach out or propel itself along. When the lactic acid vanishes surface tension overcomes the imbibition and the organism resumes its resting spherical form. According to this theory the origin of limbs and of movements comes from an accumulation of lactic acid.

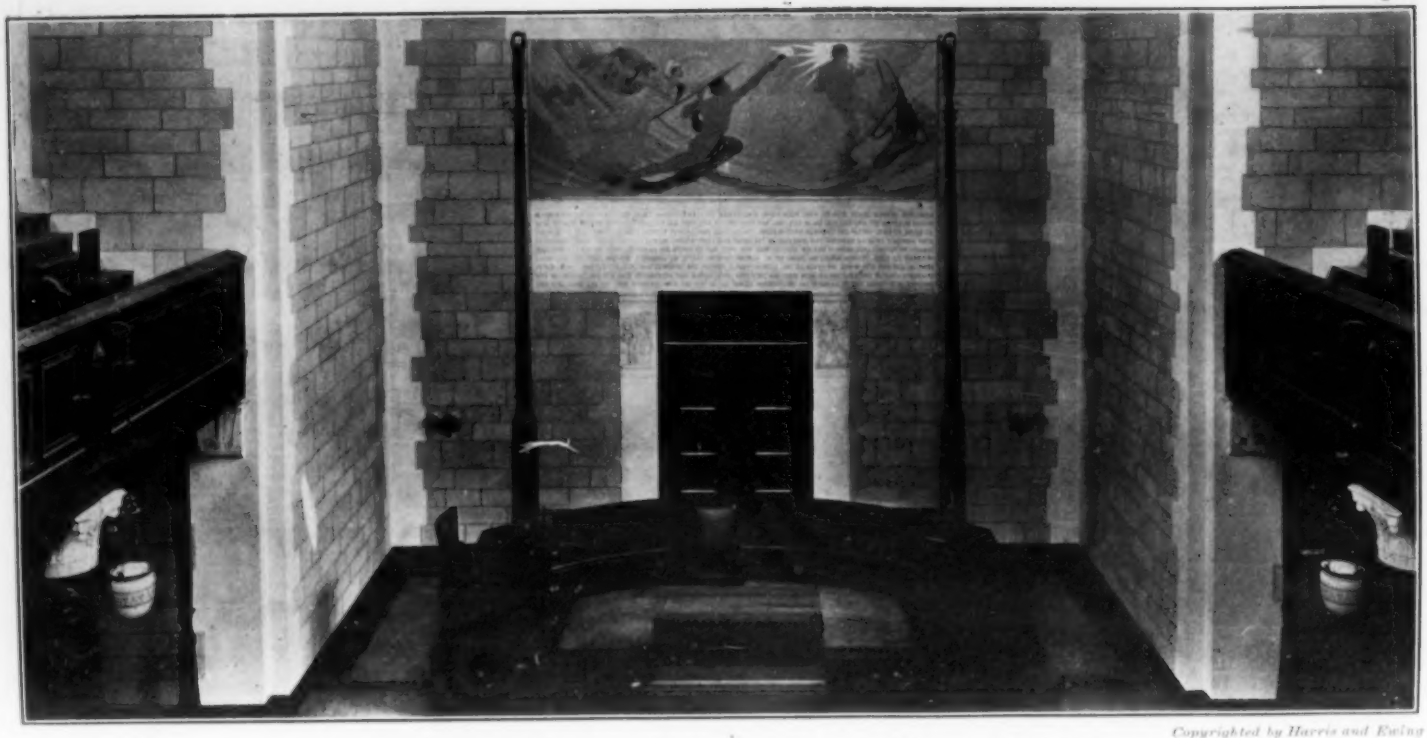
It seems to me then that there is a chain of casual connection between lactic acid formation and our conceptions of space and time. If so, it means that our metaphysics has a chemical foundation; that geometry is essentially a branch of chemistry; that astronomy likewise depends on chemistry; that Einstein's theory of a four-dimensional time-space continuum has its origin in deficient oxygen to keep down the lactic acid. In short, we have a lactic acid theory of he universe. Q. E. D.

PREDICTING THE MOVEMENTS OF ELECTRONS

THE essence of science is prophecy. Until a student of nature can tell what is going to happen beforehand his knowledge is of uncertain validity and little value.

The science of astronomy had its birth twenty-five hundred years ago when the Greek philosopher, Thales, predicted the coming of an eclipse of the sun.

To-day a new science is being born, quite as marvellous as astronomy and much more important to the world. It may indeed be called "the astronomy of the atom," since it deals with the orbits of the electrons in their revolution about the central nucleus. This reminds us of the arrangement of the solar system with the positively charged nucleus standing for the sun in the center and the corpuscles of negative electricity revolving around it. But there is this important difference. The solar system is stable and the planets pursue almost exactly the same course, century after century, fortunately for us who are living on one of them. It would be decidedly disconcerting to us, if, for instance, Mars should be carried off by a comet making the grand tour of the universe, and Saturn should suddenly drop into its place. Or if our earth should be detached from the sun and swept off through space and be drawn into the sphere of influence of some other star like Sirius, which we might not like so well as our own sun. Yet that sort of thing happens frequently with the electronic planets inside the atoms. And it has now been found possible to predict what particular orbit a loosed electron will fall into. This is possible because when an electron shifts from an outer orbit to one nearer the nucleus it sends out a flash of light of a definite color, that is to say the waves of the emitted light are of a certain length and a corresponding frequency. The "frequency" means the number of waves passing a given point in a second. The longer the waves, of course, the less the frequency.



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ROSTRUM IN THE ROTUNDA OF THE BUILDING OF THE NATIONAL ACADEMY

The frequency and wave length of the light radiated by any star or incandescent gas can be determined by the location of the bright lines in its spectrum.

Professor R. A. Millikan, of the California Institute of Technology, has recently discovered a way of stripping off one by one the outer electrons from an atom, and he can tell in advance with amazing accuracy just what sort of light will be emitted by such a stripped atom. Last year Dr. Millikan was awarded the Nobel Prize in physics for the ingenious piece of apparatus that enabled him to catch and count the loose electrons and calculate their electric charge. He has this year penetrated still further into the mystery of atomic structure. His new discovery was to have been explained to the National Academy of Sciences on the afternoon of April 29, but on account of the tragic death of Dr. E. F. Nichols while addressing the Academy that morning no further papers were read during the day. But Professor Millikan has kindly consented to give a plain account of what he has done and what it means.

THE ASTRONOMY OF THE ATOM

By Dr. Robert A. Millikan
California Institute of Technology

The world is just entering upon a period of development of atomic mechanics, or of the astronomy of the atom, which has many points in common with the period of development of celestial mechanics which occupied the two or two and a half centuries following Galileo. Celestial mechanics was made possible through the invention of the telescope. The spectroscope bears precisely an analogous position with respect to atomic mechanics. The telescope made it possible to determine the exact orbits of heavenly bodies and to check by precise observation of such phenomena as the time of eclipses the theoretical results which are consequences of the Newtonian laws. Similarly, to-day the spectroscope has furnished the physicists with means for the quantitative testing of the recently developed laws of atomic mechanics, and it is to-day furnishing as exacting proof of the orbital theory of electronic motions as the telescope furnished a century earlier for the orbital theory of the motions of heavenly bodies.

The present paper shows not merely what kind of phenomena can be predicted with the aid of the orbital theory of electrons and atoms, but with what amazing precision these predictions are verified by the test of experiment. These results have been made possible because of the development of high vacuum "hot spark" spectrometry with the aid of which we were able first in 1920 to push three or four octaves farther into the ultra-violet than preceding investigators had gone. For the sake of simplicity, I shall at first confine attention to the radiations emitted by one particular atom, namely, the atom of boron, familiar to every household because of the abundant use of boracic acid for disinfecting purposes.

The atom of boron is the fifth in the order of increasing atomic weights, hydrogen being the lightest, helium the next, lithium the next, beryllium the next and boron the next. This means that the nucleus of the boron atom contains five free positive electrons and that five negative electrons are held outside the nucleus, or just enough to make the normal boron atom electrically neutral. Of these five electrons two have been proved heretofore, and are again proved in this paper, to be close to the nucleus. The re-

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maining three are four or five times more remote from the nucleus and are called its valence electrons. For the sake of later comparison it is useful to recall that lithium possesses one of these valence electrons, beryllium two, boron three, carbon four, nitrogen five, oxygen six and fluorin seven, which is the highest number possessed by any known atom having the possibility of combining with other atoms at all.

Now the interesting property of our hot sparks, which are very high potential discharges in the highest vacua between electrodes from a fraction of a millimeter up to one or two millimeters apart, is that such hot sparks possess an extraordinary ionizing power. Mr. I. S. Bowen and myself at the California Institute of Technology have recently definitely proved that these hot sparks have the power of stripping a great many atoms completely of all their valence or outer electrons. These stripped atoms of lithium, beryllium, boron, carbon and nitrogen, for example, are then completely similar atomic structures, save for the fact that the central charge increases in the ratios one, two, three, four, five, in going from lithium to nitrogen. This is the first time that it has become possible to compare the radiating properties of such a long series of similar atomic structures and the discovery of a means of obtaining such a series has furnished the opportunity of getting some very interesting checks upon the theory of electronic orbits.

Now the theory of electronic orbits in atoms is similar to the theory of planetary orbits in astronomy save that the atoms have one restriction unknown to the former. While celestial mechanics permits of the existence of as many orbits as you please around a given central sun, atomic mechanics permits of a very limited number of orbits whose radii progress (in the simple Bohr theory) in the ratio of the squares of the numbers one, two, three, four, five, etc. Atomic mechanics also differs from celestial mechanics in the mechanism by which the existence of a particular orbit can be experimentally tested. Thus, the most exact test which astronomy offers for the correctness of hypothetical planetary orbits is the prediction of the instant of passage of two such orbits through a given line so as to produce an eclipse. If the eclipse occurs at the predicted instant, it is considered that the theory which made the predictions possible has received extraordinary quantitative support. In the astronomy of the atom, on the other hand, we can not observe an eclipse, but what we do observe is the frequency (the reciprocal of the wave-length) of the radiation emitted when an electron jumps from one of its possible orbits to another. These jumps always occur from the orbits more remote from the nucleus to those which are closer to it and the difference in the energies of the electrons in the two orbits (which I shall call the energy of the orbit itself) is found to be in every case exactly proportional to the frequency emitted. It is this frequency which the spectroscope immediately brings to light as a spectral line whose wave length, and therefore whose frequency, it enables us very accurately to measure.

The whole number of different orbits which are possible in such a simple nucleus-electron-system as is furnished by the hydrogen atom has long been accurately known experimentally, and these known orbits have been fitted beautifully and accurately into what is known as the simple Bohr theory.

This theory requires that if the charge on the nucleus should be successively given the values one, two, three, four, five, the frequencies of all the orbits would be increased in the ratios one, four, nine, sixteen,

twenty-five. Now the discovery of the possibility of stripping all the valence electrons off the atoms of lithium, beryllium, boron, carbon and nitrogen has given us the means of comparing the radiations from what are in effect simple nucleus-electron-systems in which the charge on the nucleus increases in the ratios one, two, three, four, five, provided always that we are comparing orbits in different atoms which are so remote from the nucleus that the pair of electrons which, as indicated above, is near the nucleus in all the atoms may be considered as exerting their forces as though they were in the nucleus itself.

To return now to the consideration of the stripped boron atom. When Mr. Bowen and I began to get evidence that our hot sparks were stripping the boron atoms of all their valence electrons, we set to work to predict exactly what sort of frequencies (or of wave lengths) we might expect to be emitted by the stripped boron atoms as a single electron, in being drawn into this stripped atom, began to jump between the possible orbits which ought to exist about it. Thus, on the basis of our knowledge of the spectral lines emitted by hydrogen, we predicted at once that an electron in jumping from the fifth to the fourth of these possible orbits would produce a line of just nine times the frequency of the radiation produced when the hydrogen atom electron jumped from the fifth to the fourth orbit. We computed in this way that this stripped boron atom ought to have a line whose wave length was 4,500 Angström units, that is, a line in the blue region of the ordinary visible spectrum. No such line had ever been observed with boron thus far, but no one had before worked with light like that given off by our hot sparks which one could expect would produce stripped boron atoms. So we made our exposure, developed our plate, and found our predicted line which no one had ever seen before at exactly the wave length 4,499.0, or within one part in 5,000 of the predicted spot. In other words, our predicted "eclipse" in the field of astronomical orbits had occurred at exactly the right time.

We also computed the radiation that would be produced when the electron circling around the stripped boron atom fell from the third orbit to the second and got 678 Angströms. We looked up our table of boron lines in the extreme ultra-violet which we had published last January and found that we had recorded a strong line at wave length 677 Angströms, but if this were indeed due to the stripped boron atom it ought to be, like the so-called D line of sodium, a doublet, that is, a pair of lines very close together. It had not appeared so on our old plate, but the spectrograph had not been one which could have separated this pair, even if it existed, so we built a new spectrograph of higher resolving power and took another photograph of this line and found that it was indeed a doublet, just as our orbit theory demanded, the two components of which had wave lengths of 677.01 and 677.16.

We have now brought to light all the lines which were to be expected from the stripped boron atom and by checking all of these predictions by experiment we had proved with absolute certainty that in our hot sparks we were producing stripped boron atoms.

But some one says: Are these results dependent upon your orbit theory of the motion of electrons? Thus far, not completely, but in the next stage they are completely so dependent. I have spoken of the doublets which we found produced by the stripped boron atom. Now the principal lines in the spectrum of hydrogen are also doublets, and a beautiful theory was developed by Professor Sommerfeld for explaining these doublets.

He showed that there ought to be two orbits, one circular and one elliptical, which would have exactly the same energy if it were not for the fact that the mass of the electrons in the elliptical orbit should grow greater as its speed increased in going through perihelion and smaller as it went through aphelion, and that because of the dependence of mass upon speed which is required by the Einstein theory of relativity. He further computed exactly with the aid of that theory the differences in the energies of two orbits, the one circular and the other elliptical, and found that this theory, which yielded a formula in which there were no undetermined constants at all, predicted completely and exactly the observed frequency separation of the hydrogen doublet. We now tried this relativity doublet theory upon the doublets which we had found in lithium, beryllium, boron and carbon and found that this purely theoretical formula predicted exactly the observed separations in all cases. We then predicted from this formula the separation of the doublet which ought to be produced by the stripped nitrogen atom and looking in the nitrogen spectrum found a nitrogen doublet with precisely the correct separation and at a wave length which we could also predict by our theory. We had thus brought to light a most powerful instrument with which we can now analyze the light that comes from any kind of a source, for example, a very hot star, and know at once by comparison with the theory of observed lines whether stripped atoms of a whole series of substances exist or do not exist in the sources. In this way, we have definitely proved the existence in our hot sparks of stripped atoms of lithium, beryllium, boron, carbon, nitrogen, sodium, magnesium, aluminum, silicon, phosphorus and sulphur, this last atom having been stripped of six valence electrons, phosphorus of five, silicon of four, aluminum of three, magnesium of two and sodium of one.

These methods bring to light new ways of going on eclipse expeditions in the study of the astronomy of the sub-atomic world, and they reveal new possibilities for the reading of the conditions existing in the stars. Truly, we are just now entering upon a period of the fascinating study of the astronomy of the atom, a period in which the spectroscope is the instrument with which we must bring to light wonders no less fascinating than those which the telescope has revealed in the study of the stars.

INDEX

NAMES OF CONTRIBUTORS ARE PRINTED IN SMALL CAPITALS

Aircraft, Transportation by, EDWARD P. WARNER, 383
Alcohol from a Scientific Point of View, J. FRANK DANIEL, 159
Astronomical Events in 1924, 222
Asymmetry, Development of, T. H. MORGAN, 273
Atom, the Astronomy of the, 665

Bacon, Francis, the Philosophy of, HARRY ELMER BARNES, 475
Baird, the Naturalist, C. HART MERRIAM, 588
BARNES, HARRY ELMER, The Philosophy of Francis Bacon, 475
BAUER, LOUIS A., Terrestrial Magnetism in United States, 625
BECKING, L. B., Antoni van Leeuwenhoek, Immortal Dilettant, 547
BIRKHOFF, GEORGE D., Origin, Nature and Influence of Relativity, 225, 408, 517, 616
BRETZ, J HARLEN, Modern Conceptions of Earth History, 239
BROWN, ROBERT M., Occupations in the United States, 196
Business Strategy in National and International Policy, JOHN F. CROWELL, 596

Cathode Rays, 443
CATTELL, J. MCKEEN, Interpretation of Intelligence Tests, 508
Chemical Messengers of the Body, 333
Chemistry and the Alphabet, 672
Conservation, Two Kinds of, 331
COWGILL, GEORGE R., Historical Aspects of Experimental Physiology, 401
CRAIG, WALLACE, The Dog as a Detective, 38
CRANE, T. F., Painting the Town Red, 605
CROWELL, JOHN F., Business Strategy in National and International Policy, 596
Cult and Early Economic Organization, The, HERBERT MAYNARD DIAMOND, 66

DANFORTH, RALPH E., Language as a Factor in Human Evolution, 76
DANIEL J. FRANK, Alcohol from a Scientific Point of View, 159
Democracy—Can the Masses rule the World? G. STANLEY HALL, 456
DIAMOND, HERBERT MAYNARD, The Cult and Early Economic Organization, 66
Dog as a Detective, WALLACE CRAIG, 38
DOWNING, ELLIOT R., Science Teaching in Some European Schools, 628

Eagle as National Bird, 107
Earth History, J HARLEN BRETZ, 239
Earthquakes, Prediction of, 336
Education, Use and Misuse of, 442
Electrons, Predicting the Movements of, 663
Embryology, Experimental, T. H. MORGAN, 5, 205, 273, 354, 529, 561
Endocrine Organs, R. G. HOSKINS, 257
Endocrinology, The Rôle of the Internist in, THOMAS SPRUNT, 580
Evaporation, Human, 111
EVERMANN, BARTON WARREN, The Steinhart Aquarium, 149
Evolution, Language as Factor in Human, RALPH E. DANFORTH, 76; John T. Gulick, Contributor to Evolutionary Thought, ADDISON GULICK, 83; of the Useless, 105

FAIRLIE, JOHN A., Politics and Science, 18
Forestry, Biotic Factor in, EDWARD N. MUNNS, 322

Geology and our Civilization, WARREN D. SMITH, 168
GOOD, H. G., Edward Livingston Youmans, 306
GULICK, ADDISON, John T. Gulick, Contributor to Evolutionary Thought, 83

Half Breed, ELSIE CLEWS PARSONS, 144
HALL, G. STANLEY, Can the Masses rule the World? 456
HOSKINS, R. G., Functions of the Endocrine Organs, 257
HUMPHREYS, W. J., The Weather Service of the United States, 372

Intelligence, Scores, GUY M. WHIPPLE, 496; Tests, Interpretation of, J. MCKEEN CATTELL, 508

Japan, The Dawn of Western Science in, KAN KIKUCHI, 113
JENNINGS, H. S., Centenary of Joseph Leidy, 427

KEEN, W. W., "Social Nuisances," 318
KENOYER, L. A., Plant Life of British India, 48
KIKUCHI, KAN, The Dawn of Western Science in Japan, 113
Lactic Acid Theory of the Universe, 661
Language as a Factor in Human Evolution, RALPH E. DANFORTH, 76
Leidy, Joseph, Centenary of, EDWARD S. MORSE, H. S. JENNINGS, WILLIAM B. SCOTT, 422
LOCKYER, WILLIAM J. S., Growth of the Telescope, 92

MACCURDY, GEORGE GRANT, Recent Developments in Prehistory, 467
MERRIAM, C. HART, Baird the Naturalist, 588
Microbes, 559
MILLIKAN, ROBERT A., The Astronomy of the Atom, 665
MORGAN, T. H., Heredity of Embryonic Characters, 5; Localization of Median Plane of Embryo, 205; Development of Asymmetry, 273; One Embryo from Two Eggs, 354; Two Embryos from One Egg, 529; The Development of Egg-fragments, 561
MORSE, EDWARD S., The Joseph Leidy Centenary, 422
MUNNS, EDWARD N., The Biotic Factor in Forestry, 322

Nichols, Ernest-Fox, 659

Occupations in the United States, ROBERT M. BROWN, 196

Painting the Town Red, T. F. CRANE, 605
PARSONS, ELSIE CLEWS, Half-Breed, 144
Pasture, SPENCER TROTTER, 394
Physiology, Historical Aspects of Experimental, GEORGE R. COWGILL, 401
Plant Life of British India, L. A. KENOYER, 48
Politics and Science, JOHN A. FAIRLIE, 18
Prehistory, Recent Developments in, GEORGE GRANT MACCURDY, 467
Printers, Early, The Debt of Medical Science to, JAMES J. WALSH, 181
Progress of Science, E. E. SLOSSON, 105, 216, 331, 441, 555, 659
Proteins, 555

Radium, Life History of an Alpha Particle from, ERNEST RUTHERFORD, 337
Relativity, Origin, Nature and Influence of, GEORGE D. BIRKHOFF, 225, 408, 517, 616
RUTHERFORD, ERNEST, Life History of an Alpha Particle from Radium, 337

Science, and Politics, JOHN A. FAIRLIE, 18; in Japan, Dawn of Western, KAN KIKUCHI, 113; and Pseudo-Science, 216; Service of, 223; Teaching in Some European Schools, ELLIOT R. DOWNING, 628
Scientists, Need of Integration of Attitudes among, KIMBALL YOUNG, 291
SCOTT, WILLIAM B., Leidy's Paleontological and Geological Work, 433
SHAPLEY, HARLOW, The Distribution of the Stars, 449
SLOSSON, E. E., The Progress of Science, 105, 216, 331, 441, 555, 659
SMITH, WARREN D., Geology and our Civilization, 168
Social Nuisances, W. W. KEEN, 318
Soy, 109
SPRUNT, THOMAS, The Internist in Endocrinology, 580
Stars, Distribution of the, HARLOW SHAPLEY, 449
Stature in the United States, Distribution of, CLARK WISSLER, 129
Steinhart Aquarium, BARTON WARREN EVERMANN, 149

Telescope, Growth of, WILLIAM J. S. LOCKYER, 92
Temperament, 557
Terrestrial Magnetism in the United States, LOUIS A. BAUER, 625
Transportation by Aircraft, EDWARD P. WARNER, 383
TROTTER, SPENCER, Pasture, 394
Turkey, as National Bird, 107

Vacuum, there's Something in it, W. R. WHITNEY, 639
Van Leeuwenhoek, Antoni, Immortal Dilettant, L. B. BECKING, 547
Vitamine, Fertility, 447

WALSH, JAMES J., Debt of Medical Science to Early Printers, 181
WARNER, EDWARD P., Development of Transportation by Aircraft, 383
Weather Service of the United States, W. J. HUMPHREYS, 372
WHIPPLE, GUY M., Intelligence Scores, 496
WHITNEY, W. R., The Vacuum, 639
WISSLER, CLARK, Distribution of Stature in the United States, 129
Woman's Control of the Future, 219

Youmans, Edward Livingston, H. G. GOOD, 306
YOUNG, KIMBALL, Need of Integration of Attitudes among Scientists, 291

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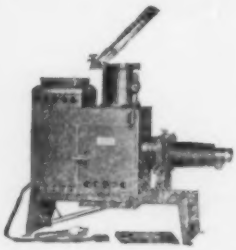

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